MANPOWER DEVELOPMENT FOR NEW NUCLEAR ENERGY PROGRAMS

by

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Submitted to the Department of Nuclear Science and Engineering
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Abstract

In the spring of 2012, nine countries were seriously considering embarking on nuclear energy programs, either having signed contracts with reactor vendors or having made investments for the development of infrastructure for nuclear energy. Several more countries are expected to initiate nuclear energy programs during this decade. The new nuclear power plants that will be built in these countries will require well-trained personnel in numbers sufficient to ensure their safe and efficient operation, maintenance and regulation.

The approaches to manpower development of the American, French, Japanese, Korean, Chinese and Indian nuclear industries are described and analyzed. Lead times for the development of education and training infrastructure and for training workers are found to be of the order of several years. This necessitates forecasting manpower requirements and planning ahead. Differences between these countries in their approaches to manpower development are observed. These include differences of job specialization, educational qualifications, and workforce size. Such differences are driven by differences in the structure of the industry, regulatory pressures, historical factors and future expectations. Comparisons are also made between the nuclear, coal, and airline industries in the U.S.

These findings have important implications for the institutional design of new nuclear energy programs. Differences in the objectives, expected scale, and pace of development of these programs mean that systems of manpower development need to be tailored to each country. A hierarchy of strategic and implementational decisions informing the creation of manpower development systems for newcomer countries is presented.

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Chapter 1

Introduction

In 2008, the International Atomic Energy Agency (IAEA) reported that at least 50 countries had approached the Agency expressing an interest in nuclear energy [12]. In the aftermath of the events at the Fukushima Daiichi plant in March 2011, several of these countries have affirmed their intention to proceed with their plans. Of these, three have already signed agreements with reactor vendors for purchasing reactors and six others have started developing infrastructure needed for a new nuclear energy program. It is likely that many more countries will join their ranks in the years to come.

The nuclear power plants that will be built over the next few decades in these countries will require well-trained personnel in numbers sufficient to ensure their safe and efficient operation. Some of these countries will build a few reactors and retain that capacity while others like China and India will rapidly expand their use of nuclear energy.

Traditionally, countries embarking on nuclear energy programs have previously built research reactors and these have provided opportunities for education and training at least on a modest scale. However, several of the countries which are now planning nuclear energy programs have no plans to build and operate research reactors first. These countries will therefore need to establish new research and educational programs to train operators, engineers and managers to work at nuclear power plants as well as officials to regulate the use of nuclear energy. The presence of a well-trained and adequate manpower base will be essential in reaching milestones such as project planning, implementation, and reactor operation without delays and associated cost overruns.

How should a newcomer country create a workforce for its nuclear energy program?

This is the central question that this work attempts to answer. We think of the question of creating a workforce for a new nuclear energy program as the design of a system of institutions and linkages between them. These linkages take the form of flows of people, knowledge and funds.

Each newcomer country must make a set of strategic and implementational decisions that lead to the creation of a manpower development system.

Organization of this work

The findings and conclusions in this work are informed by the experiences of countries that already have nuclear energy programs.

A series of case studies comprise the first part of this thesis. Chapters 2, 3 and 4 explore the manpower policies of the US, French, Korean, Japanese, Chinese and Indian nuclear energy programs. Countries that have followed similar manpower policies and have similar institutional organizations are grouped together. This facilitated an examination of cross-national differences in manpower policies which is the subject of discussion of Chapter 5.

Emerging nuclear energy countries can learn several lessons from the experiences of these six nuclear energy programs. These lessons, presented in Chapter 6, taken from three groups of countries are applicable to different stages of a new nuclear program.

In an attempt to identify whether there are similarities in workforce development across different industries in the same country, a comparative study of the US nuclear, airline and coal industries was undertaken. This is the subject of Chapter 7 which is the concluding chapter of Part 1 of this thesis. Through this comparative study we extract an important lesson for newcomer countries: they should not attempt to precisely mimic the occupational composition and size of the specialized workforces in countries such as the U.S. or France. A low degree of specialization and large numbers of high-skilled workers may be needed at the outset to receive tacit and codified knowledge from the vendor country.

Chapter 8 focuses on questions of forecasting manpower requirements, lead times for training different kinds of workers and implications for education and training. Chapter 9 presents a methodology or a decision-making hierarchy for the design of a manpower development system. Four such possible systems, representative of newcomer countries, are presented. We do not find that there is a unique solution, or, in other words, a one-size-fits all system of workforce development that will serve all newcomer countries equally well. We expect the 'ideal' system for each newcomer country to look different. Finally, Chapter 10 identifies unanswered questions that may be areas for future work.

There are tremendous opportunities for newcomer countries to learn from the experiences of existing nuclear energy programs. However, this learning must not take the form of unquestioning imitation , but rather, intelligent sense-making.

Part I

Case Studies and Lessons Learned

Chapter 2

Manpower Policies of the US Nuclear Energy Program

This case study begins by tracing the evolution of the manpower policies of the US nuclear energy program. The first section of the case study focuses on the qualitative aspects of developing manpower for a new technology. The section of this case study that traces manpower policies up to the 60s draws heavily on the work of Kuhn [13]. Subsequent developments are pieced together from DOE , IAEA and PNNL reports.

Numerical data, when provided, are used to illustrate trends in the size and occupational composition of the nuclear workforce. The second half of the case study focuses on the current manpower requirements of the nuclear industry, specifically manpower needs of nuclear plants and the NRC. Factors that influence manpower requirements are discussed along with efforts aimed at training manpower. Finally, an assessment of historical trends and current manpower requirements is made to identify challenges that the industry faces and strategies for confronting these challenges.

2.1 Historical background

2.1.1 The World War II period: 1940 - 1945

Following the discovery of nuclear fission in 1939, both American and foreign-born scientists foresaw it being used as a source of energy for power reactors, naval vessels and nuclear weapons. Albert Einstein, Enrico Fermi, Edward Teller, Victor Weisskopf, Leo Szilard and many others tried to interest the government in both the civilian and defense applications of nuclear energy. Arthur Compton explained that the push for the exploration of fission as a source of energy for nuclear weapons and power reactors came from these foreign born scientists rather than American ones because they looked at the government differently than American scientists at the time "[s]ince the major European universities operated on government funds, the Europeans expected their research in the nation's interest to find its best support also from this source." Conversely, at that time American scientists were unaccustomed to dealing with the government and there existed no channels by which these scientists could have consulted with the government to mobilize scientific manpower for national purposes.

Growing interest in the wartime applications of nuclear fission and the persistent efforts of the scientific community resulted in the establishment of the National Defense Research Organization (NDRC) and soon after, the Office of Scientific Research and Development [13].

The continuous exchange of information needed to create and then transfer laboratory experiments into full scale operation was hindered by the need for secrecy. Information was spread by word of mouth and special committees were convened to facilitate an exchange of ideas. The effectiveness of group problem solving and the need for interdisciplinary collaboration and accelerated technical development for the creation of a nuclear weapon led to the creation of the Manhattan Engineering District (MED). The central mission of the MED, the development of a nuclear weapon, came to be known as the Manhattan Project.

This period saw a focused interest in the military rather than the civilian applications of nuclear fission. However, the creation of the NDRC, the Office of Scientific Research and Development and the MED opened channels of communication between the government and the scientific community. The 1940s for the first time witnessed large-scale collaborations between scientists, engineers and the government. The creation of an institutional infrastructure through which the government could support interdisciplinary scientific research would, in the coming decade, prove to be invaluable for mobilizing manpower for the exploration of the civilian applications of nuclear energy.

2.1.2 The Atomic Energy Commission (AEC) : 1946 - 1953

In 1946 the Atomic Energy Commission (AEC) was created under the Atomic Energy Act. In its initial years the AEC faced shortages of scientists, engineers and managers. It had taken over the nuclear weapons development program of the MED and lost close to 6000 scientists and engineers between 1946 and 1950 [14]. These scientists and engineers came from academic backgrounds and were returning to their respective universities at the end of the war. Concerned by the high turnover of manpower and intent on developing better nuclear weapons, the AEC initially ignored the development of nuclear power and even discouraged its use as an energy source for naval vessels.

The first push for nuclear energy from within the AEC came from Lewis Strauss who later became its chairman. Outside pressure from both the the military, potential vendors and utilities, spurred the AEC to develop its first reactor program in late 1948. In doing so, the AEC authorized General Electric (GE) and Westinghouse to build a land-based breeder reactor and a submarine reactor respectively. AEC also established a Division of Reactor Development. It must be pointed out that the perceived uranium shortages had caused the AEC to initially focus solely on its military program and later caused it to emphasize research and construction of breeder reactors. In 1952, the AEC tasked scientists at MIT to evaluate the economic costs of nuclear reactors. The results of this project, Project Dynamo, showed that nuclear energy had the potential to become economically competitive without having to rely on plutonium sales to the government.

The AEC now acknowledged the need for a definite industrial policy for the development of nuclear energy and recommended a revision to the Atomic Energy Act of 1946 in order to allow private groups and businesses to own and operate nuclear power facilities. The original act had conferred a monopoly on all nuclear energy activities to the government. As the interest of private industry in nuclear energy grew, the question of manpower was once more brought to the fore and manpower shortages were anticipated. Members of the Commission publicly stated that the rate at which nuclear energy could be harnessed to produce electricity would depend on the availability of engineers and scientists to solve technical problems [13].

2.1.3 Private Companies Enter the Nuclear Energy Industry: early 1950s

In 1953, President Eisenhower presented the Atoms for Peace initiative in a speech to the United Nations and initiated the creation of the International Atomic Energy Agency. The following year saw a revision of the Atomic Energy Act that allowed private companies to build and operate nuclear power plants.

With the revision of the Atomic Energy Act, companies were now eager to gather information on nuclear energy. However, the dissemination of this information was restricted by secrecy regulations. Companies soon realized that the quickest way to access this information was to hire scientists and engineers who had worked in the field. However, at the time there were a limited number of people who had done so. Some businessmen were of the view that it was the responsibility of the AEC to train scientists, technicians and engineers for the private companies to hire. They supported this claim by emphasizing that the AEC was the largest employer of workers in the field of nuclear science and owned almost all the nuclear facilities [13].

By 1953, the AEC had worked out a three-pronged program for increasing the manpower available for the US nuclear energy program. First, it assisted colleges and universities in introducing studies in nuclear technology and funded the design and construction of research reactors. Second, in order to increase interest in the field of nuclear energy, the AEC tried to attract teachers and lecturers who would hold seminars and discussions at high schools and colleges. Third, the AEC undertook to retrain scientists and engineers and update their skills and established the Oak Ridge School of Reactor Technology and also the International Institute of Nuclear Science and Engineering at the Argonne National Laboratory as part of the Atoms for Peace program. Both institutions trained new AEC employees as well as workers hired by private companies. It was not the intention of the

AEC to compete with universities that were beginning to set up nuclear engineering programs but to supplement their efforts in educating nuclear scientists and engineers. By 1954, twelve universities had begun to offer courses in nuclear engineering and by 1962 the number had exceeded a hundred.

Besides educating new nuclear engineers through university programs, a large portion of the demand for workers was met through on-the-job training of workers who were competent in related fields and who already had a technical education. The AEC encouraged its contractors to carry out on-the-job training and and bore up to 80% of the associated costs [15, 13]. AEC research contracted to universities having nuclear engineering programs also served as an indirect means to train engineers and scientists.

It wasn't scientists or engineers, however, but skilled workers who formed the single largest occupational group in the nuclear industry [16]. Tighter tolerances and complex machines made it necessary to retrain both craftsmen and technicians. Companies such as Du Pont , Westinghouse and GE set up welding schools for retraining welders. Similarly, courses were also organized for process production operators and nuclear instrument maintenance workers. Courses thus organized for skilled workers were intensive courses that generally lasted under a year. These training programs were neither formal nor run on a continuing basis. They were set up shortly before a plant or manufacturing facility was scheduled to go into operation and terminated once the demand for technicians had been met [13].

In 1955 the Power Division of Reactor Development made projections of manpower demand. These estimates showed that the bulk of new jobs created by the nuclear energy industry in the coming decade would employ technicians and craftsmen rather than scientists and engineers. This shift in occupational composition was supposed to reflect a maturation of the nuclear industry which would soon move from research and development to production and operation of nuclear reactors. The initiative taken by the AEC to train nuclear scientists, engineers, and technicians, promote university nuclear engineering programs and forecast manpower needs ensured that the nuclear industry did not face manpower shortages as it expanded [13, 17, 16].

2.1.4 Manpower Policies - Reactor Vendors: mid 1950s

Companies, instead of adopting explicit manpower policies, allowed these policies to be shaped by the managers they hired and by the development goals they set. A developmental goal once set created manpower needs that had to be met. In the early 1950s, the constantly evolving reactor development goals of General Electric (GE) resulted in a large turnover rate. GE had initially developed the breeder reactor but abandoned it in favor of a sodium-cooled converter (which became the first reactor to be used on a naval submarine, the Seawolf) [18]. After developing this converter design GE, in 1952, switched to a boiling water reactor which would be sold to utility companies. However switching from one reactor design to another was frustrating for the scientists and engineers who had devoted much time and effort to a particular reactor concept. GE faced a serious manpower shortage in 1953 when scientists and engineers who had worked on the sodium cooled convertor reactor left GE when it made the switch to the boiling water design. Recognizing the cause of attrition, GE decided to channel its manpower resources for the development of a single reactor concept for the utilities and altered its recruitment policies to transfer and advance workers from within [13] .

Westinghouse followed an approach very different from GE's. Westinghouse did not enter the nuclear energy industry until it accepted a naval contract to build a water cooled reactor. Westinghouse decided that, unlike GE's scientific approach to reactor development that involved exploring several advanced reactor designs, it would follow an engineering approach and channel its resources towards developing water-cooled reactors only. Westinghouse worked in close cooperation with the navy, particularly with Admiral Rickover and his men. Unlike GE, Westinghouse organized training courses in nuclear technology for its management. In 1957, the first prototype commercial power reactor, a pressurized water reactor (PWR) built by Westinghouse, was put into operation at Shippingport. The reactor was originally built under contract with the AEC and developed for the Naval Reactor Program. Westinghouse's engineering approach proved to be effective and by the end of 1961 it had built 24 reactors for submarines, 10 for ships and had contracts to build 32 more submarine reactors [18]. Westinghouse's experience showed that focusing all available manpower resources towards the rapid development of a single reactor design and later, its standardized production, was effective for moving nuclear energy technology to the production stage.

2.1.5 Manpower Policies - Electric Utilities : late 1950s

Over the years, electric utilities had kept operating costs low by adopting lean manpower policies. Electric utilities, like reactor vendors, did not have explicit long-term manpower policies but met the manpower needs that were created as a result of economic pressures or technological changes.

Complex tasks had, over time, been broken down into routine procedures that were easily performed by technicians and electric utilities did their best to employ only as many workers as strictly necessary. Electric utilities did not undertake research and development and saw these activities as expensive and time consuming because they did not yield immediate returns on investment. The utilities were dependent on manufacturers of equipment to carry out research and development and would then incorporate innovations from the outside by modifying routine operating procedures where needed. Years of routine operation had eroded the ability of utilities to adapt to and use new technologies.

Electric utilities were slow to express interest in nuclear energy because they did not see it as economically competitive. Ultimately, the AEC's announcement that it would build power reactors if electric utilities failed to do so spurred the utilities to action. When the construction of the first nuclear power plants began, these utilities continued to believe that their policy of minimizing staffing levels would suffice. They saw nuclear reactors as a new heat source and were certain that they would be able to develop routine procedures for operating their new plants. This complacency on the part of the electric utilities ended when the AEC announced licensing requirements for nuclear power plants.

Utilities would now have to prove that their employees would be able to operate nuclear reactors and handle ancillary equipment by obtaining licenses for plant operators before the plant construction was finished. Relying solely on on-the-job training was no longer an option. Utilities realized that training courses that focussed on the theory and operation of nuclear reactors were needed. There was also the possibility that some operators would not pass the AEC's licensing examinations. In order to be prepared for this contingency, more workers than would be needed to operate the power plant would have to be trained.

Utilities realized that the operation of nuclear reactors required extensive instrumentation, computers, and remote controlled devices as well as high levels of tolerance and technicians with higher skill levels would be needed. Electric utilities now turned to consultants to help them in setting up training programs for new workers. However, most utilities did not begin to train workers until the construction of the plant had begun. This was done in order to minimize the risk of training men who would not be needed in the event that the project was terminated before construction began [13] and also possibly to reduce the costs of retaining idle workers.

During this period, electric utilities invested in nuclear power plants assuming that their lean manpower policies would suffice. However, the licensing requirements imposed by the AEC coupled with the need to understand the operational and manpower requirements of a new technology resulted in a shift away from the traditional approach of minimizing staffing to reduce operating costs. Even so, the utilities over time would learn how to break down complex operating procedures into sub-tasks that could be performed by technicians rather than scientists and engineers. This is the subject of discussion of following sections.

2.1.6 A Maturing Industry? 1962 - 1980

The period from 1962 to 1977 saw a manifold increase in the installed nuclear capacity in the US from 730 MWe to 47,013 MWe or an increase from 4 to 65 nuclear reactors. Employment in reactor maintenance and operation alone increased from 633 to 17,270 workers while the total number of workers in the nuclear industry increased from 127,000 to 227,000 [18].

This period also saw the gradual occupational shift that had been forecasted by AEC officials in the 1950s. Reactor vendors were shifting their focus from development to the construction of reactors. The number of scientists and engineers employed by the industry (both by reactor vendors and utilities) was on the decline whereas the numbers of technicians and craftsmen were gradually increasing. In 1972, technicians comprised 59.4% of the workers in reactor operations and maintenance. The interim years saw periods when the proportion of technicians in the workforce declined. Planners attributed this to a shortage of technicians in those years which forced utilities to hire engineers and scientists [13].

In 1962, the majority of engineers in nuclear power plant operation and maintenance had received undergraduate or graduate degrees in mechanical engineering. By 1977, however, nuclear engineering had come to be recognized as a new discipline and nuclear engineers exceeded the number of mechanical engineers involved in plant operation and maintenance [19, 20]. The large number of scientists and engineers still employed by the industry as a whole indicated that highly skilled, trained and educated workers would continue to play an important role in the nuclear industry. This was also testament to the complexity of nuclear energy technologies whose operation could not be broken down easily into routine procedures to which electric utilities were previously accustomed.

The nuclear plants built during this period were turnkey. Reactor vendors partnered with architect engineers to build plants that were handed over to the utility company for operation. Reactor testing and startups were carried out by experienced personnel employed by reactor vendors. Startup and test engineers simultaneously trained new plant operators. The practice of using startup and test engineers supplied by reactor vendors continued until the late 1970s when utilities began training their own workers for plant startup and testing. Startup engineers were in great demand and often left vendors and the navy to become highly-paid independent contractors. These engineers joined the utilities after plant startups reached a peak in the mid 1980s and declined thereafter [21].

In 1974, the Energy Reorganization Act dismantled the AEC and in its place created two new federal agencies: the Energy Research and Development Administration (ERDA), which became the Department of Energy (DOE) in 1978; and the Nuclear Regulatory Commission (NRC). The abolition of the AEC and the creation of two separate organizations, the NRC and DOE, was done in response to the criticism that the promotion and regulation of nuclear energy should not both be done by a single body.

The economic downturn in 1974 impacted the nuclear industry which began to slow down. By the end of 1974 orders had been placed for the construction of 233 reactors. However by 1976, the number of reactors planned or under construction had decreased to 166 and would decrease further after the accident at the Three Mile Island (TMI) plant. The TMI accident also affected enrollments in university nuclear engineering programs. In the Fall of 1979, enrollments in undergraduate nuclear engineering programs were 10% lower than the previous year. There were fears that low enrollments in nuclear engineering programs would result in manpower shortages in the coming decade.

This proportion of engineers and technicians in the nuclear workforce increased during this period. Enrollments in university nuclear engineering programs increased until 1979. The number of nuclear engineers grew until they exceeded the number of mechanical engineers employed by nuclear plants. There was also a progression from research to commercialization and economies of scale were seen in manpower utilization which can be attributed to learning effects. Operation of multi-unit plants also contributed to better utilization of manpower.

The decrease in enrollments in university nuclear engineering programs would have caused a shortage of manpower for the nuclear industry had its planned expansion continued.

Plant capacity factors rose continuously from the 1960s and have consistently been over 90% since 2000. Higher capacity factors increased the workload for both operations and maintenance staff and, as will be discussed in the next section, contributed to an increase in staffing levels in the 1990s.

2.1.7 Economic Pressures and Staffing Decisions 1980 - 1990s

The decade from 1980 to 1990 saw an increase in capacity factors accompanied by mounting workloads for nuclear plant workers. Operations, maintenance and engineering staffing levels increased gradually to meet the increasing workload and training staff too was increased. Additional control room shifts were added at several plants and the total number of shifts ranged from 5 to 7 in control rooms across nuclear plants. Administrative staffing was also increased for the better management of a growing workforce. Plants were under constant scrutiny and in interviews conducted for a case study by the Pacific Northwest Laboratory, plant staff reported feeling pressures "not only from the Nuclear Regulatory Commission (NRC), but from the Institute of Nuclear Power Operations (INPO), the Nuclear Management and Resources Council (NUMARC), and the Public Utilities Commissions (PUCs) as well."[22] These were pressures to improve safety of operations, increase training and design basis reviews. Regulatory requirements or pressures that tended to create more work also resulted in increased staffing levels. Utilities initially began to rely on contractors to meet increasing workloads but eventually resorted to hiring additional full time employees to reduce high costs of hiring contractors in large numbers. Plants also developed new overtime policies to meet growing workloads.

During this period plants felt conflicting pressures: economic pressures that tended to reduce staffing levels and regulatory pressures that tended to increase them. The result was an overall increase in staffing levels.

A review of the history of the US nuclear energy program from a manpower perspective shows that the organization and policies of the industry underwent several changes over the course of half a century of reactor design, construction and operation. Right from the outset, the multidisciplinary nature of nuclear energy research necessitated collaborations between scientists and engineers from diverse backgrounds. The need for accelerated technical development for the creation of a nuclear weapon forced the government, the scientific and the military community to work jointly. New channels of communication created between these factions set the stage for future collaborations for the civilian applications of nuclear energy.

Multi-disciplinary collaborations also gave rise to a new discipline - nuclear engineering. The AEC took the initiative to train nuclear scientists and engineers, aided universities in setting up nuclear engineering programs and began collaborations between universities and government-run research facilities. The foundations laid by the AEC for cooperation between universities and the government-run national laboratories are continued by the DOE today.

Scientists and engineers initially experimented with several reactor concepts but both economic competitiveness and manpower problems forced reactor vendors to limit research and development to fewer reactor concepts. Although research on advanced reactor designs continues today, all operational power reactors in the US are either PWRs or BWRs. Limiting research and development to fewer reactor concepts reduced the turnover rate. Furthermore, standardization of reactor technologies accelerated the construction of reactors and later allowed utilities to share operation and maintenance information and learn from each others' experiences.

The rest of this case study summarizes education and training initiatives for training the nuclear workforce. Manpower requirements for nuclear power plants are presented and factors affecting staffing are identified. Finally, strategies for the future are presented.

2.2 Manpower Needs of US Nuclear Industry

This section of the case study reviews the manpower needs of the nuclear industry for the operation, maintenance and regulation of nuclear plants. Manpower needs of nuclear plants and the NRC are presented here. However, it must be pointed out that the manpower needs of the nuclear industry are not limited to the personnel needed by the NRC and the nuclear plants but also include the manpower requirements of the national laboratories, reactor vendors, contractor firms, and companies that supply instrumentation equipment and ancillary services.

Following sections begin by comparing plant staffing levels in order to determine factors affecting nuclear plant manpower requirements.

2.2.1 Manpower for Nuclear Plants

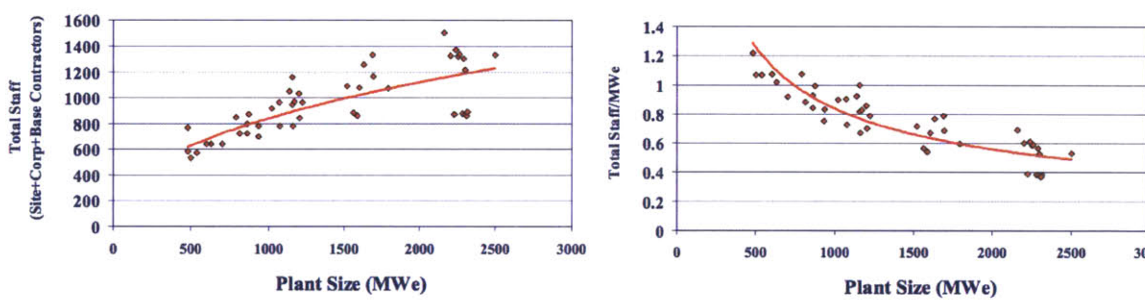
The US has 104 operating nuclear reactors, 35 of which are BWRs and 69 PWRs. These reactors are operated as plants made up of either a single reactor or multiple collocated reactors. Nuclear plants directly employ 129,249 workers. Of these workers 74.79% are on site employees, 13.26% are offsite corporate employees and 11.95% are contractors [23].

This section discusses the trends in nuclear power plant staffing across the industry. Levelized staffing, expressed as staff/MWe, is compared to determine factors that affect power plant staffing.

2.2.2 Comparison of Nuclear Plant Staffing Levels Across the Industry

There are two three-unit plants in the US. The other 102 plants are operated as one and two unit plants. In 2009, the average one and two unit plant employed 731 workers and 1142 workers respectively. A 2009 study on nuclear plant staffing reported that average plant staffing had increased by 3% from the previous year. 65% of all nuclear plants in the US contributed to an increase in this staffing which was attributed to an increase in hires to offset impending retirement of personnel. Additional hires were also made in order to meet NRC Fitness for Duty Requirements put in place to avoid worker fatigue. The study also reported that the last decade had seen a decline in maintenance and construction staffing with operations and plant staffing undergoing few changes [24].

Figure 2-1 shows total and levelized staffing as a function of plant size expressed as MWe. As seen in Figure 2-1a, total plant staffing increases with an increase in plant size However, as seen in Figure 2-1b larger plants benefit from economies in plant staffing. For single unit plants, total plant staffing does not scale with the installed capacity, resulting in reductions in levelized plant staffing with an increase in the size of the reactor. If the larger plant size is the result of multiple reactor units at the same site, economies in plant staffing result from sharing maintenance staff across reactor units, centralization of managerial activities or having a single control room for multiple reactor units.



(a) Total plant staffing and plant size

(b) Levelized plant staffing and plant size

Figure 2-1: Total and Levelized staffing as a function of plant size[2]

Lower staffing levels have been recorded for plants owned by utilities that operate multiple plants. There has been a trend over the last decade of consolidation of nuclear power plants under single utility companies. Ten utility companies now own more than 70% of the installed capacity. Consolidated ownership of nuclear plants has facilitated better information transfer across reactor units and a reduction in the number of offsite corporate staff needed per unit of installed capacity. This has ultimately resulted in more efficient power plant operation reflected in higher capacity factors and shorter refueling outages. Figure 2-2 shows levelized staffing as a function of the number of reactors operated by the same utility.

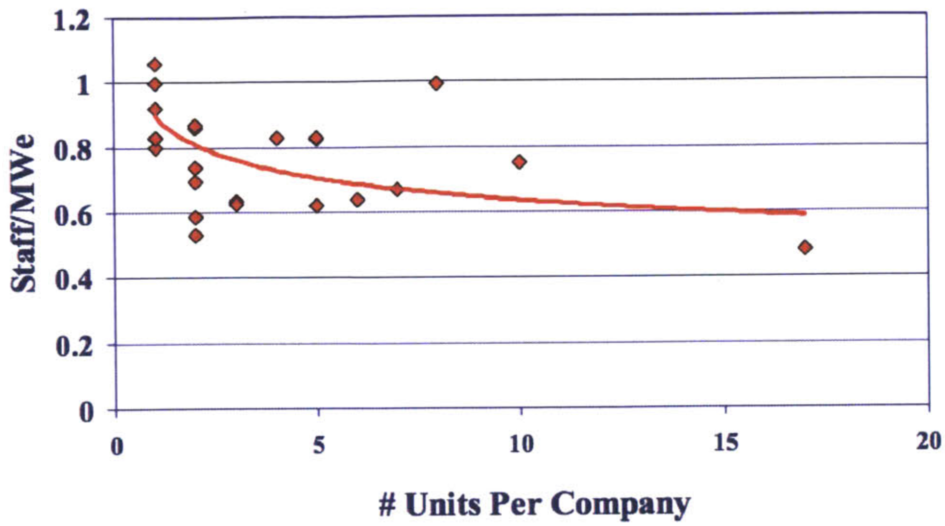
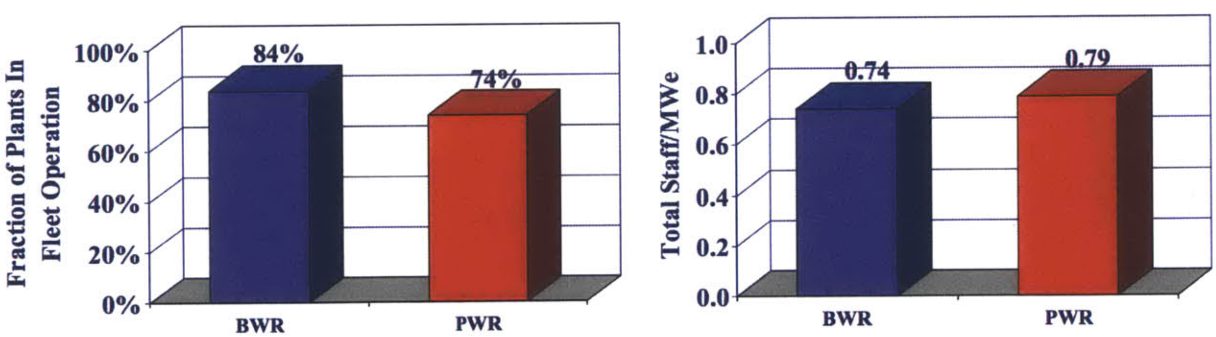


Figure 2-2: Levelized staffing and the number of reactor units operated by a company [3]

2.2.3 Effect of Reactor Type on Plant Staffing

Plant type does not appear to have a significant impact on plant staffing. As seen in Figure 2-3a 84% of the BWRs in operation are operated as multi-unit plants. Larger plant size and operation of multiple reactor units at the same site results in a lower levelized staffing. As discussed earlier, this lower levelized staffing can be attributed to centralizing activities and sharing staff across reactor units.



(a) PWRs and BWRs: Fleet operation

(b) PWRs and BWRs: Levelized staffing

Figure 2-3: Fleet operation and levelized staffing [3]

2.2.4 Educational Qualifications of Plant Workers

We now attempt to develop a reasonable estimate that can be used to comment on the current and future manpower needs of the US nuclear industry. There is a lack of data on the educational backgrounds and ultimate employment of workers not just in the nuclear industry but for the electric power sector as a whole [25] and, as will be discussed later, monitoring and gathering this data is an area that requires immediate attention.

Table 2.1 shows an estimate for the number and educational qualification of plant workers. As discussed earlier, single-unit plants in the US employ close to 800 workers. The staffing levels presented in Table 2.1 are descriptive of a single unit plant. In this estimate, nuclear engineers make up just over 3% of the workers at the plant. While low, this estimate is similar to NEA's that pegged nuclear engineers at under 10% of the workers at a nuclear plant [17]. This scarcity of nuclear engineers in the utility workforce may be the result not of a lack of demand but a lack of supply of nuclear engineers.

Table 2.1: Education and training skills required for nuclear plant personnel [8]

Workforce category	Approximate number required
Civil Engineers	5
Computer, electrical and I&C engineers	20
Mechanical engineers	15
Nuclear engineers	25
Project/plant engineers	30
Chemistry Technicians	20
Maintenance technicians*	135
Radiation protection and rad waste handling technicians	35
Security personnel	70
Trainers	35
All other personnel	335
Total	800

*Includes I&C technicians, mechanics

Table 2.2 shows the total number of nuclear engineers, technicians and operators in the US and the number employed in electricity generation, transmission and distribution.

Table 2.2: Nuclear engineers, operators and technicians [9, 10, 11]

Occupation	Total Employed	Employment in electricity transmission, generation and distribution
Nuclear engineers	18610	6760
Nuclear reactor operators	5080	4300
Nuclear technicians	6960	3140

Assuming that all 6760 nuclear engineers employed in electricity generation, transmission and distribution are employed at nuclear plants, and dividing this total number of nuclear engineers by 104 (the number of nuclear reactors in the US) we find that approximately 65 nuclear engineers are needed for the operation of a single reactor[1]. Repeating this calculation for nuclear technicians and operators shows that around 65 nuclear engineers, 42 nuclear operators and 31 nuclear technicians are required for the operation of a single reactor. The staffing levels thus found for nuclear engineers and operators can be taken as upper limits for the number of these personnel required for operating

[1]This is an upper-limit because, as discussed earlier, larger plants benefit from manpower economies.

a single reactor. However, both historical trends, recent reports and the estimate showed in Table 2.1 indicate over a 100 technicians are needed for normal plant operation and maintenance.The unexpectedly small number of nuclear technicians reported by BLS can be attributed to the ambiguous definition of a 'nuclear technician' . Defining the roles of workers at nuclear plants in a manner that is consistent across the industry is important both for quantifying and recruiting the number of workers who will be needed.

The future manpower needs of the US nuclear industry are discussed after a brief discussion on the manpower needs of the NRC.

2.2.5 Manpower for the NRC

Figure 2-4 shows NRC staffing as the ceiling on full time equivalent employees over the last decade. Of the 3992 personnel that the NRC currently employees 3023 are involved in Nuclear Reactor Safety, 911 work in Nuclear Materials and Waste Safety and 58 work in the Office of the Inspector General [4]. In 1990 when the US had an installed nuclear capacity of 98.0 GWe, 4015 personnel were employed by the NRC [26]. Present day NRC staffing levels are lower both on an absolute and levelized basis. The increase in NRC staffing over the last decade can be attributed to an increase in license renewal and power uprate reviews.

Historically, just under half of the NRC staff have been nuclear engineers [26].

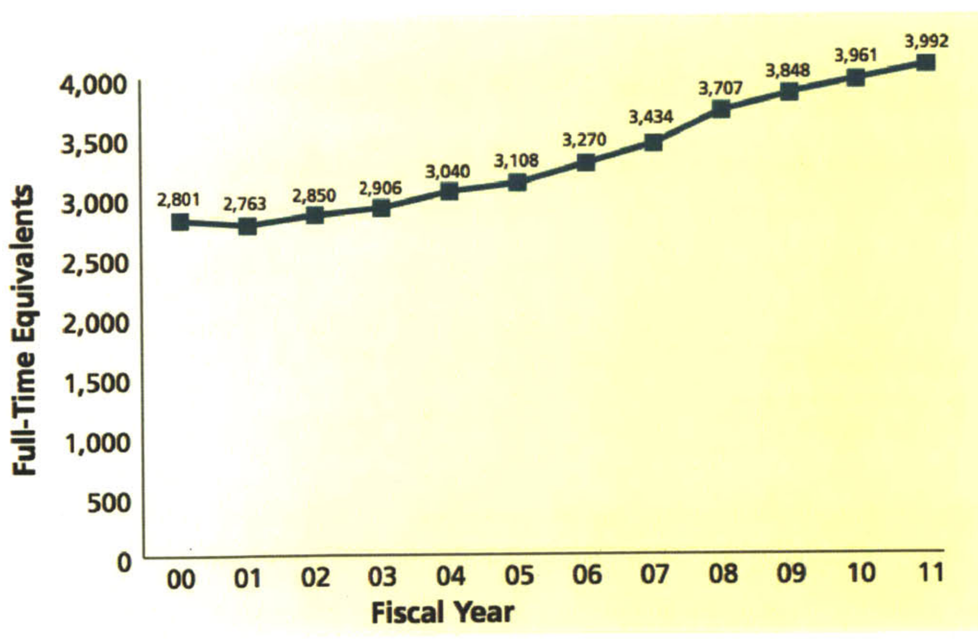


Figure 2-4: NRC personnel ceiling [4]

2.2.6 Future Manpower Needs of the US Nuclear Industry

Recent studies and surveys have forecasted personnel attrition rates for the nuclear industry ranging from 30% to 50% of the total workforce over the next five years [27, 17, 28]. Going with the worst-case scenario of 50% attrition indicates that close to 65,000 workers currently employed by nuclear utilities will retire by 2017. If we assume that median age of NRC staff is similar to that of workers in the nuclear industry, then the NRC can expect an attrition of 2000 workers over the next five years. This brings the total expected attrition to roughly 67,000 workers or a loss of 13,400 workers a year.

For reasons discussed earlier, it is difficult to estimate the number of technicians that the nuclear industry will need to hire in the coming years. In 2010, the NEI reported utilities would need 27,800 new technicians by 2015. It is unclear what portion of this demand has already been met. Utilities will need to hire close to 3380 nuclear engineers[2] and 2150 reactor operators [3] will be needed over the course of five years. In addition to this, the NRC too might need to hire 1000 nuclear engineers. Thus, the utilities and the NRC alone will need roughly 876 nuclear engineers and 430 reactor operators a year for the next five years.

Utilities reportedly hired 9680 workers in 2009 [29]. While this large-scale hiring is both expected and necessary, it is unlikely that utilities will be able to hire staff in increasingly large numbers unless the worker pipeline grows to match demand. Universities, community colleges, government agencies and utilities themselves have an important role to play in sustaining and increasing the size of the nuclear workforce.

It is important to note the estimates presented here reflect workforce needs for plants that are currently operating. In the absence of immediate utility-level and industry-wide initiatives that ensure long-term supply of trained manpower , a future expansion of installed nuclear capacity will be limited by the availability of manpower.

2.3 Meeting the Manpower Needs of the US Nuclear Industry

Universities, community colleges and electric utilities themselves have played an important role in educating and training the nuclear workforce. The extent and nature of these training efforts is discussed here.

[2]This number was estimated by dividing in half the number of nuclear engineers who are currently employed in electricity generation, transmission and distribution as reported by BLS in 2010

[3]This number was estimated by dividing in half the number of reactor operators who are currently employed in electricity generation, transmission and distribution as reported by BLS in 2010

2.3.1 Universities - Training Nuclear Engineers

There was a decrease in the number of university nuclear engineering programs since the mid 1980s, and this was accompanied by a reduction in the number of research reactors. This trend has been reversed over the last five years and some universities have either established or reestablished nuclear engineering programs. 32 university departments presently offer nuclear engineering programs.

Enrollment in nuclear engineering programs is affected by public opinion towards nuclear energy as well as investments in nuclear engineering research and education. Enrollments decreased by 10% soon after the TMI accident but have increased since 1990 and in particular since 1997 in response to an increase in DOE investments in nuclear engineering research and education [15]. Figure 2-5 shows the number of bachelors, masters and doctoral nuclear engineering degrees awarded over the last decade. Also shown in this figure is an estimate for the number of nuclear engineers that utilities and the NRC will need to hire annually in order to compensate for attrition over the next five years.

In 2010, 80 nuclear engineers - 1 doctoral, 49 bachelor and 30 masters degree holders joined nuclear utilities [5]. This is less than 10% of the nuclear engineers that utilities need to hire annually in order to compensate for attrition. An rapid increase in student enrollment rates in nuclear engineering university programs is needed to meet the workforce demands of the nuclear utilities.

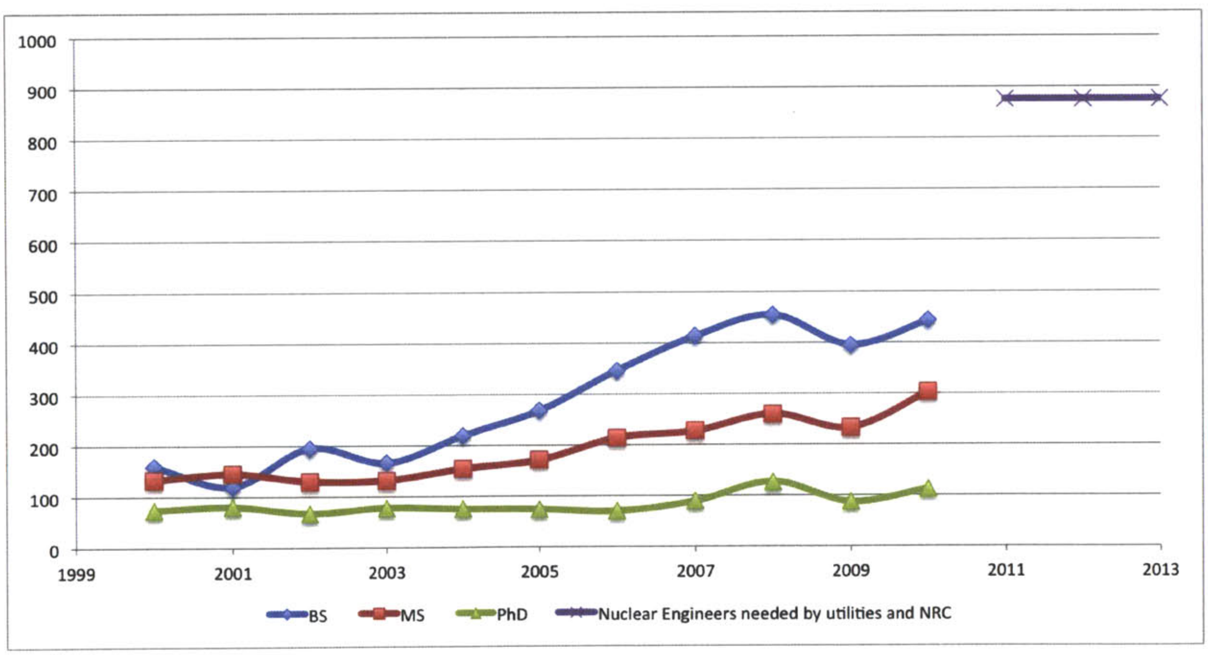


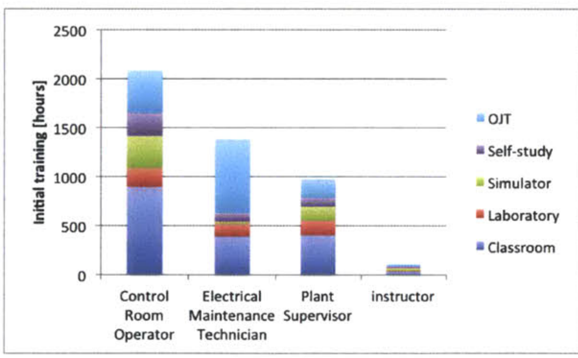
Figure 2-5: Nuclear engineering degrees [5] and an estimate of additional nuclear engineers needed by the utilities and the NRC every year

2.3.2 Community Colleges - Training Technicians

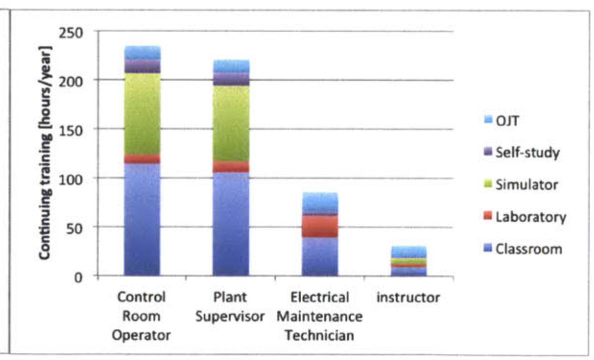
Recognizing the impending workforce attrition, the Nuclear Uniform Curriculum Program (NUCP) was initiated by the NEI Work Force group in 2008. This program currently includes 42 community colleges. Through this program, utilities have been working with community colleges to develop an industry-recognized standard curriculum for training maintenance, non-licensed operator, chemistry technicians and radiation protection technicians through two year programs [30]. The Program aims to reduce the training time for workers and also increase worker mobility by awarding certification recognized industry-wide. NEI estimates that 27,800 new technicians will be needed at nuclear utilities by 2015. Data on graduation rates at community colleges participating in this program have not been published but like university programs, these programs too will need to grow rapidly until each participating community college produces over 100 technicians annually on average.

2.3.3 Electric Utilities - Training Nuclear Reactor Operators

Nuclear plants in the US have in-house training programs for training management, reactor operators technicians and instructors. Figure 2-6 shows the duration and type of initial and continuing training given to plant workers at US utilities. As seen in Figure 2-6, classroom and simulator training for reactor operators is the primary focus of these in-house training programs. Training given to electrical maintenance technicians, although substantial, is less formal and given on-the-job [6].



(a) Initial training



(b) Continuing training

Figure 2-6: Training U.S. plant workers [6]

Reactor operators must be licensed by the NRC for the operation of a specific reactor. Nuclear plants have dedicated onsite training facilities and staff for training new reactor operators and retraining licensed operators. Operator training covers plant start up and shut down, base load plant operation as well as accident scenarios. The need to train operators to respond to accident conditions and practice reactor start up and shut down precludes using the power reactor for training purposes and necessitates the use of simulators. As discussed in an earlier section, utilities in total will need to train close to 430 reactor operators annually and each plant[4] must obtain licenses for 6 to 10 new operators annually.

2.3.4 Benchmarking - Optimizing Plant Staffing

Nuclear plants can meet their manpower needs by a combination of hiring new workers and reducing the required plant staffing.

Electric utilities have historically shared data on plant operation and maintenance. Utilities owning nuclear power plants also share this information and have over the years benchmarked staffing and operational costs at their plants with those owned by other utilities. Extensive benchmarking within the US nuclear industry has resulted in increasingly consistent plant staffing levels and convergence to a few nuclear power plant organizational structures.

All electric utilities in the US are members of the Electric Utility Cost Group (EUCG) . The Nuclear Committee of the EUCG meets twice every year to share data and industry practices gathered from member utilities [31]. In the absence of centralized manpower planning, organizations such as the EUCG along with consulting firms have played an important role in disseminating information on staffing and operational costs and quantifying the manpower needs of nuclear utilities.

Nuclear utilities, vendors, INPO, EPRI and several consulting firms have participated in studies aimed at optimizing plant staffing. Optimal staffing is defined as "the minimum staff needed to meet plant operational safety and business objectives in all plant operating modes." [2] A study on optimizing plant staffing conducted by EPRI showed that staffing reductions of up to 36% could be achieved at nuclear plants in the US. These reductions in staffing can be achieved by adopting standardized processes and procedures , increased on-power maintenance, using multi-disciplinary work teams and increasing automation for surveillance and testing [2].

It is clear that the future manpower needs of electric utilities will have to be met through a combination of training new workers and reducing staffing levels. Precedent shows that utilities have been averse to innovation, invested little in research and development and forged few partnerships with universities. Impetus for increasing nuclear engineering education at the university level has come largely from the DOE in the form of research grants, scholarships and fellowships. The initiation of NUCP in 2008 is likely to have a positive impact on the supply of technicians for the nuclear utilities. However, utilities have expended little effort in partnering with universities. While the lack of utility interest in the development of new reactor designs is understandable, research in the area of reactor operations and management could be contracted to universities.

However, utilities have historically outsourced questions of organization and staffing to consulting firms rather than to universities. There is a need for utility-university partnerships not only to better communicate the manpower needs of utilities to nuclear engineering departments but also to

[4]There are 65 nuclear plants in the US

re-introduce innovation to utilities to prepare them for operational and management changes that will be needed to build and operate new reactors.

2.4 Manpower Policies for the Future

Having assessed the supply and demand for manpower in the nuclear industry, we now summarize measures that can be taken, and in some cases that are already being taken, by individual utilities and the industry a whole in order to meet current and future manpower needs. As examples , the Palo Verde nuclear plant has instituted internship and worker rotation programs [32], the Tennessee Valley Authority has developed guidelines for assessing attrition and its impact on loss of knowledge [33] and Entergy uses a systems dynamic tool to forecast attrition due to retirements and bases its hiring strategy on the results of its model [34].

2.4.1 Policies for Individual Utilities

Just over half a century of nuclear power plant operation has repeatedly shown that utilities need to develop and follow explicit manpower policies. Had present day utilities done this, the problem of attrition they face today could have been avoided.

Manpower policies at the utility level should be aimed at quantifying attrition, recruiting new workers, knowledge management initiatives and forging partnerships with universities and community colleges. Each of these are discussed in greater detail below.

Quantifying Attrition Although several attempts have been made to quantify the industry-wide attrition of the nuclear workforce, similar initiatives are needed at the utility level. Utilities must identify the areas which will be worst hit by retirement-related and other attrition. Identification of these areas and the magnitude of expected attrition is necessary for implementing knowledge management measures and recruiting workers in adequate numbers. Instead of solely monitoring age demographics of workers at their plants, utilities should survey employees (anonymously, if necessary) to accurately forecast attrition due to retirements.

Recruiting New Workers The question of attrition and recruitment of new workers should be looked at in the context of the electric power industry as a whole. A recent study suggested that close to one third of the 400,000 people employed in electricity generation, transmission and distribution will retire in the coming decade [25]. It is in this environment of electric power industry-wide workforce attrition that the nuclear industry will need to recruit new workers in increasing numbers. The NUCP initiated in 2008 is a step in the right direction and its success will be critical for providing technicians to the nuclear industry.

Nuclear utilities will need to work particularly hard to become appealing workplaces for graduates of nuclear engineering departments. Surveys of young professionals have shown that the new generation of technical workers are looking for jobs that allow flexibility, independence, inclusion in the decision making process and minimal bureaucracy at the workplace [28]. Other factors affecting willingness to work are location and salary [35]. New-hire development, rotation programs and education reimbursement programs will appeal to the new generation of nuclear engineers and scientists who are considering joining utilities. In order to sustain the worker pipeline, utilities should ramp up existing internship programs, create new ones and hire undergraduate interns from a variety of engineering departments. Hands-on work and mentoring offered to this demographic through summer internships could not only increase the worker pipeline for nuclear utilities but also increase enrollments and retention of students in nuclear engineering departments.

Lastly, utilities should hire as many of the new workers as soon as possible in order that these new workers can serve as understudies and deputies to workers who are about to retire. While knowledge management measures will go a long way towards preserving undocumented knowledge, on-the-job training by experienced workers will likely allow the much needed rapid transfer of knowledge.

Knowledge Management Measures Knowledge management constitutes passing on lessons learned and undocumented knowledge of plant operation from the existing to the new generation of plant operators. Knowledge management programs such as the one initiated by the Tennessee Valley Authority are aimed at identifying knowledge that is being lost, the criticality and consequences of losing that knowledge, and measures that can be taken to avoid such losses . These measures include but are not limited to interviewing employees who are about to retire and documenting explicit as well as implicit knowledge, transferring knowledge to new workers and re-engineering procedures to ensure that knowledge lost does not affect plant operation [36].

Knowledge management efforts should also extend to gathering detailed information on plant startup and testing practices. The most recent US NPP commissioning was that of the Watts Bar Unit 1 in 1996 [21]. As discussed earlier, independent construction and startup engineers joined utilities after the reactor startups declined. Startup and testing procedures known to these engineers should be recorded and included in curricula for training startup and construction engineers for new plants that will be built over the coming decade.

Partnerships with Universities and Community Colleges Several utilities have already established partnerships with community colleges through NUCP. However, utilities can contract research to universities and provide feedback on curricula to communicate their workforce needs. A survey of 40 Chief Nuclear Officers showed that nuclear plants would like to employ engineers who have practical hand-on experience and acquired through plant visits or simulator training [37]. It is this kind of information that must be transmitted through a continuing dialog between universities and utilities.

2.4.2 Policies for the Nuclear Industry as a Whole

Quantifying Manpower Needs and Defining Manpower Roles Recently, efforts have been made by both utilities and consulting firms to quantify workforce shortages and manpower needs of the nuclear industry. These efforts have focussed attention on the problem of large-scale attrition that the industry faces today. It is imperative that even after the present attrition problem is solved, the nuclear industry as a whole continues to monitor its manpower needs, quantifies expected manpower shortages and communicates this information to government agencies such as the BLS and DOE. Furthermore, it is equally important to periodically survey the educational backgrounds of plant workers in order to identify which strategies for training new workers have been most effective. The EUCG, which already gathers data on plant staffing and O&M costs, could feasibly expand its database and services to encompass the aforementioned activities.

Nuclear utilities also need to collectively define the classification and responsibilities of plant personnel. As discussed earlier, nuclear technicians are an integral part of the nuclear workforce. However, the ambiguous definition of a 'nuclear technician' hinders data collection by agencies such as the BLS. Furthermore, studies indicate that the development of industry-wide standards for worker roles and responsibilities as well as certification of these workers will increase worker mobility and willingness to join the nuclear industry [25].

Benchmarking Continued industry wide benchmarking efforts should be aimed at identifying factors that cause differences in staffing levels at plants operating essentially identical reactors. Benchmarking efforts, currently led by the EUCG, will enable plants to reduce staffing needs. This can , in part, ameliorate the problem of worker shortages.

Public Outreach Industry-wide public outreach is needed to create interest in nuclear engineering at the school level and also to improve the public acceptance of nuclear energy. Both ANS and DOE have led outreach activities by participating in designing high school science curricula, offering training courses to teachers and organizing seminars for students [15].

This study shows that this is not the first time that the nuclear industry has faced imminent manpower shortages. The nuclear industry has, in the the past, devised quick fixes to address such shortages by setting up temporary training schools and pursuing aggressive recruitment strategies. However, the nuclear industry today is much larger than it was in the 1950s when it first faced these shortages and more lasting measures will be needed to maintain and increase the size of the nuclear workforce. The latter part of this chapter focused on the future manpower needs of the US nuclear industry and estimates of the numbers of nuclear engineers, operators and technicians that will be needed over the next five years are discussed. However, besides these workers, utilities will also need to hire electrical, chemical and mechanical engineers, craftsmen, managers and security personnel. Upcoming power uprates and the potential for new build mean that the utilities will have to learn to do more with fewer workers or maintain their current workforce despite large scale attrition. Either strategy will require that utilities overcome their decades-long aversion to change and manpower planning to develop long-term manpower policies.

Chapter 3

Manpower Policies of the French, Japanese and Korean Nuclear Energy Programs

3.1 Introduction

The previous chapter traced the evolution of manpower policies in the US nuclear energy program to the present day. Present and future manpower needs of the US nuclear energy industry were assessed along with the infrastructure for training the nuclear workforce. A clear imbalance in the supply and demand for manpower was observed. This imbalance is the result of myopic manpower policies. Aggressive cost control measures implemented by US utilities beginning in the 1990s resulted in hiring freezes at nuclear utilities. While this strategy reduced operating costs, it signaled to college-bound students and newly minted engineers and scientists that the US nuclear industry had stopped expanding and was unwilling to hire. As a result, enrollments in university nuclear engineering programs declined steadily until DOE intervention in the form of research grants and scholarships began in 1997.

Today, the median age of the nuclear workforce in the US hovers around 50 and it is expected that close to half the US nuclear workforce will retire in the next five years. Even in the absence of new build, the US nuclear industry will require a huge influx of scientists, engineers, technicians and craftsmen. However, few nuclear engineering graduates are willing to join the nuclear utilities, preferring instead to work for DOE contractors, the Federal Government and consulting firms.

Utilities have initiated collaborations with community colleges to meet their burgeoning manpower needs. The success of these utility-community college partnerships along with an increase in enrollments in university nuclear engineering programs will be essential for meeting the manpower needs of the US nuclear industry.

We now turn our attention to the nuclear energy programs of France, Japan[1] and the Republic of Korea (referred to as 'Korea' hereafter) . Although the French nuclear energy program is older by just over a decade, both France and Korea began large scale expansion of nuclear energy and construction and operation of PWRs in 1970s and in both cases the supplier country was the US and the reactor vendor, Westinghouse. The similarities between the French and the Korean programs do not end here. Both countries have a centralized nuclear energy program under which all nuclear plants are owned and operated by a single utility - Korea Hydro and Nuclear Power Company (KHNP) and (Electricité de France) EDF in Korea and France respectively.

The origins of the Japanese nuclear program are similar to that of the French. After the moratorium on nuclear research was lifted in 1952, Japan moved quickly to build its first nuclear plant housing a gas cooled reactor that used natural uranium as fuel. The reactor was based on a UK design. Like France, Japan's decision to initially invest in the GCR was based on considerations of the difficulty in procuring enriched uranium. Also like France, the Japanese switch from GCRs to LWRs was based on the cost competitiveness of the latter. However, unlike both Korea and France, Japan followed a program of building and standardizing both PWRs and BWRs. Although the Japanese nuclear industry is made up of ten utilities, each utility operates a single reactor type. Kansai Electric Power Company and the Tokyo Electric Power Company (TEPCO) respectively are the largest of these utilities and operate PWRs and BWRs respectively.

All nuclear plants in Japan, France and Korea have multiple reactor units, with as many as 7 reactors at a site in each country. Conversely, in the US only two nuclear plants have three reactors at a site [2].

Ownership and operation of standardized, multi-unit plants by large utilities has afforded manpower economies for all three countries. These and other factors such as the training infrastructure, manpower needs and manpower planning for both nuclear energy programs are discussed here. Additionally, some preliminary comparisons of manpower policies of French, Japanese and Korean utilities with those of American are highlighted. Chapter 5 will further build on these comparisons and offer reasons for cross-national differences in training and staffing.

[1]The study of manpower policies of the Japanese nuclear industry will draw on literature published before the accident at the Fukushima Daiichi plant. Following the TMI accident in the US, changes in regulatory policies and the creation of INPO led to an overhaul of the education and training of nuclear plant workers. It is highly likely that when (and if) the Japanese reactors are restarted, the economic and safety regulatory environment in which they operate will undergo changes that will impact manpower policies. For this reason, this work will not speculate on what these changes will be or their impact on manpower planning but rather focus on the manpower development activities of the Japanese nuclear industry prior to March 2011.

[2]However, following the construction of two AP1000 units at the Vogtle site, the largest nuclear plant in the US will have four collocated reactors.

3.2 Stimulus for Nuclear Energy

A lack of domestic reserves of fossil fuels and a rapidly increasing demand for electricity prompted France, Japan and Korea to expand their nuclear energy programs. The French nuclear energy program traces its beginnings to 1945 when the CEA (Commissariat à l'Energie Atomique) was established. The Japanese nuclear program was restarted in 1952 with the Atomic Energy Act of 1955 providing a legislative framework for it. The Korean nuclear energy program was born three years after the Korean war with the establishment of the Atomic Energy Section (AES) in 1956.

Government agencies in all three countries saw an immediate need to improve the public acceptance of nuclear energy. Without favorable public opinion, it would not be possible to site the new plants or recruit workers in sufficient numbers.

French government agencies linked the nuclear energy program to national energy security and marketed nuclear reactors as being a 'French technology' [38]. Korea, on the other hand, held exhibitions in six Korean cities to inform the public . The central theme was the peaceful applications of nuclear energy and the intention was to allay public fears. These national campaigns for improving public perceptions of nuclear energy were successful and both countries were able to recruit scientists and engineers to kick-start their nuclear energy programs. While available literature does not specify what public acceptance measures were undertaken in Japan, the success of such measures (especially in the wake of the devastation caused at Hiroshima and Nagasaki) was surely instrumental in siting the first nuclear plant and recruiting manpower.

3.3 Training the First Generation of Nuclear Plant Workers

France

France, developed its first reactor - a heavy water cooled design and, subsequently, gas cooled reactors indigenously. Unlike Korea, France trained its nuclear scientists and engineers domestically. Nuclear engineering programs were introduced in French universities at the graduate level. The Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA) and EDF also set up in-house training programs to train researchers and plant workers. The first nuclear plant workers came from EDFs existing power plants and were retrained [18]. French utilities reported spending almost equal amounts of time on training and plant operation in the initial years [39].

Japan

Japan too retrained coal plant workers for its nuclear plants. However, most interesting about the initial years of the Japanese nuclear energy program is the way in which manpower was used to transfer knowledge from research organizations to the vendors and utilities. The Power Reactor and Nuclear Fuel Corporation (PNC) had been established in 1967. Its primary function was R&D in nuclear technology and disseminating this information to both vendors and utilities. Nuclear industry wide budgetary constraints and manpower shortages led to the PNC loaning its employees to the Japan Nuclear Fuel Company, the Japan Atomic Power Company and the utilities themselves. This transfer of personnel was not exclusively unilateral. In some cases, agencies receiving personnel 'on loan' would in exchange send their own personnel to the PNC [40]. The porosity of these institutions to exchanges of personnel and therefore knowledge likely played an important role in accelerating Japan's program of localizing and standardizing BWR and PWR technology. The PNC also sent its personnel to Korea to aid the nuclear energy development effort there.

Korea

Inadequacy of domestic educational infrastructure prompted the Korean government to send its scientists and engineers to the US, UK, Germany, France, Japan, Italy and Canada for education and training. These students predominantly pursued engineering and physics degrees. Unexpectedly, of the 234 people sent abroad between 1955 ad 1964, only 150 returned to Korea. This attrition was not unique to the nuclear industry. This brain drain problem was overcome by imposing return obligations on those who were sent abroad on government scholarships. Scientists and engineers who returned to Korea after completing their education, along with international experts played instrumental roles in setting up nuclear engineering programs at Korean universities. By 1979, four Korean universities had established nuclear engineering programs [41].

The nucleus of internationally trained engineers and scientists and international experts selected the reactor designs that would be built at the first Korean nuclear plant. Meanwhile, anticipating the manpower needs for plant operation, KEPCO re-trained workers at existing thermal power plants.

Unlike in the US, where private utilities were slow to recognize the importance of education and training, France, Japan and Korea began training nuclear scientists, engineers and plant operators well before plant construction. The certainty of construction of nuclear plants and the importance of nuclear energy to national development goals explains the early initiative taken in these countries to train workers both domestically and internationally. Also, as we will later see, training given to French, Japanese and Korean plant workers was broad and worker rotation programs that exposed new hires to several areas of plant operation were not uncommon. Only recently have American utilities begun rotation programs for training new plant workers.

3.4 Choosing and Developing Reactor Technologies

France

France initially designed and developed gas cooled reactors indigenously. Low capacity factors and high generation costs coupled with problems at the EDF3 reactor at Chinon are cited as reasons for the switch to PWR technology. Before the switch, a divide already existed between CEA whose primary function was research and development of reactor designs and EDF, the architect-engineer and plant operator. EDF favored the switch to PWRs whereas CEA opposed it. The final decision made in favor of PWRs caused worker unrest and hundreds of CEA workers went on strike in 1969 [38]. Despite the rough transition period, EDF signed contracts with Westinghouse, FRAMATOME and a group of Belgian firms for the construction of PWRs at the Chooz and Tihange plants [18]. Following this, three series or thirty-four of the 900 MWe PWRs were built in succession. Standardization of reactor technology not only reduced construction lead times but also enabled knowledge transfer from older to newer plants. Furthermore, having a single reactor technology made it possible to train plant operators and technicians centrally. By 1980, EDF had set up 12 training schools for training 5000 technicians and engineers annually. Following this training, workers were trained onsite. During reactor commissioning workers also received training from the vendor firm [18].

Japan

Japan's first power reactor was a GCR. However subsequent commercial plants were LWRs based on American technology. TEPCO and Kansai[3], the largest electric utilities in Japan built and operated BWRs and PWRs respectively. Two training schools were set up for training BWR and PWR reactor operators. [4]

The BWRs and PWRs were based on GE and Westinghouse designs respectively. The first PWR units were built on a turnkey basis with progressively increasing participation by Mitshubishi. GE and Westinghouse continued to act as the main contractors during the 1960s. In the 1970s this responsibility shifted to Japanese companies (Mitsubishi, Hitachi and Toshiba) who were now the main contractors with the American companies now acting as the subcontractors [42]. The construction of the nuclear plants in the 1960s for which Japanese companies were subcontractors provided training opportunities for Japanese workers. This approach of initially building turnkey plants and transitioning to increasing involvement of domestic companies was successfully replicated by Korea.

[3]Kansai Electric Power Company is referred to as Kansai rather than KEPCO in order to avoid confusion with the Korea Electric Power Company (also KEPCO)

[4]JAPCO built both a PWR and a BWR in addition to the first GCR

Korea

Korea too had decided to build PWRs but was reluctant to hire private construction firms as the main contractors for plant construction. Involvement of private firms in the construction of Korea's first research reactor had caused delays [15]. At this time heavy and chemical industries too were at an early stage of development. Mindful of this, Korea constructed its first three nuclear plants on a turnkey basis with phased participation of domestic companies. Korean technicians and engineers participated in non-destructive testing and civil engineering work for the second and third reactors. A domestic architect-engineer firm was created in the form of Korea Nuclear Engineering and Services (KNE). KNE was the subcontractor for the fifth Korean NPP.

Finally, in the 1980s a reversal took place with domestic companies taking on the responsibility of the main contractor and foreign companies working as subcontractors. The Korean strategy of initially limiting participation of domestic manpower in plant construction, gradually increasing the responsibilities of Korean firms that had initially been subcontractor firms that worked under the supervision of the main contractor (Westinghouse) resulted in rapid technology transfer. On-the-job training given to Korean engineers, technicians and craftsmen during the construction period resulted in the successful localization of PWR technology. Following this, like France, and Japan, Korea too followed a program of plant standardization and built 950 MWe PWRs in succession until it developed its own variants on the design.

Interestingly France, Japan and Korea, through a process of standardization in reactor construction and operation, adapted and developed American reactor technology to produce their own LWR designs. Nuclear energy today produces 75%, 30% [5] and 31% of the electricity consumed in France, Japan and Korea respectively. All three countries are now exporters rather than importers of reactor technology.

3.5 Current institutional Organization of the Nuclear Energy Program

We pause here to briefly lay out the institutional organization of the French, Japanese and Korean nuclear energy programs before discussing education and training of the nuclear workforce. The institutional framework of these nuclear energy programs will later be drawn upon both to highlight education and training measures in each country but also to explain cross national differences in these measures.

[5] before the accident at the Fukushima Daiichi plant

France

The French nuclear energy program is organized as follows. The CEA, a public corporation, is the primary R&D organization. It carries out research in the field of reactor design, fuel cycles, and waste disposal. AREVA, formed by the merger of Cogema, Technicatome and Framatome in 2001, is the sole French reactor vendor. CEA and the French state are its main shareholders. All nuclear reactors in France are operated by a single utility, EDF. GDF Suez has equity ownership in the Chooz and Tricastin plants and also operates reactors in Belgium. ASN, is the safety regulator. It is an independent agency led by five commissioners who are appointed by the French President and Senate. Established recently in 2006, it has been tasked by the French government with the regulation of nuclear power and radiation protection of nuclear plant workers and the public at large.

Japan

A merger of Japan Nuclear Cycle Development Institute (JNC) and Japan Atomic Energy Research Institute (JAERI) resulted in the creation of the Japan Atomic Energy Agency (JAEA) under the Ministry of Education, Culture, Sports, Science and Technology. JAEA like the CEA is the primary R&D organization. Mitsubishi, Hitachi and Toshiba are the reactor vendors. TEPCO, Kyushu, Chubu, Tohoku, Shikoku, Kansai, Chugoku, Japan Electric Power Company, and Hokkaidu are utilities that operate nuclear plants. Of these TEPCO and Kansai are the largest. Regulation of nuclear power is carried out by the Nuclear and Industrial Safety Agency (NISA) which is part of the Ministry of Economy, Trade and Industry (METI).

Korea

Korea Atomic Energy Research Institute (KAERI) is the R&D organization, vendor and architect-engineer for nuclear plant construction. KHNP, a subsidiary of the Korea Electric Power Company (KEPCO), is the sole utility that operates nuclear plants. KEPCO monopolizes electric power generation and distribution in Korea. The Nuclear Safety and Security Commission (NSSC) is the independent [6] regulatory authority modeled after the NRC. The Korea Institute of Nuclear Safety (KINS) provides technical support to the NSSC.

3.6 Education and Training

France

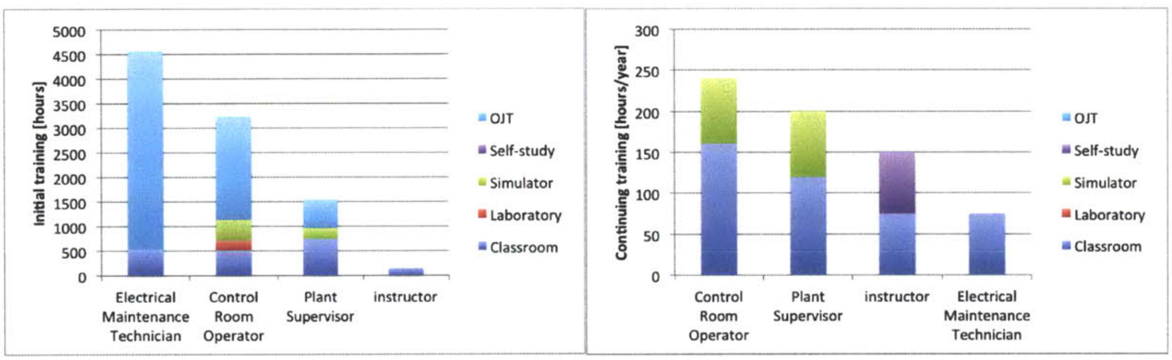
French universities along with the main stakeholders in the nuclear energy program - CEA, AREVA, EDF, and GdF Suez – train nuclear plant workers. The French education system consists largely of

[6] unlike its predecessor Nuclear Safety Commission (NSC) which was under the Ministry of Education, Science and Technology (MEST)

public universities and engineering schools. Specializations in nuclear engineering are offered only at the graduate level. Research projects pursued by graduate students are often sponsored by EdF and AREVA and can involve internships at these organizations. GDF Suez offers a one year program combining on-the-job training and classroom learning for its nuclear trainees. On-the-job training is carried out in collaboration with AREVA and EDF [15]. AREVA through the AREVA university trains engineers, executives and managers. In addition to a campus in France, AREVA University has campuses in the US and in Germany.

EDF has its own program for training nuclear reactor operators. All newcomers to the Nuclear Generation Division and the Engineering Division are trained at the Academy for Operations. Training courses are offered for nuclear reactor operators and engineers consisting of introductory and specialized courses as well as periodic courses for retraining.

Figure 3-1 shows the duration and nature of training of French nuclear plant workers.



(a) Initial training

(b) Continuing training

Figure 3-1: France: Training plant workers [6]

Additionally, the National Institute for Nuclear Science and Technology (INSTN) was set up by the CEA in 1956 in order to train technicians, engineers and researchers by offering specialized courses is nuclear science and technology. INSTN also offers vocational and professional training courses for professionals from the CEA and the nuclear industry [15].

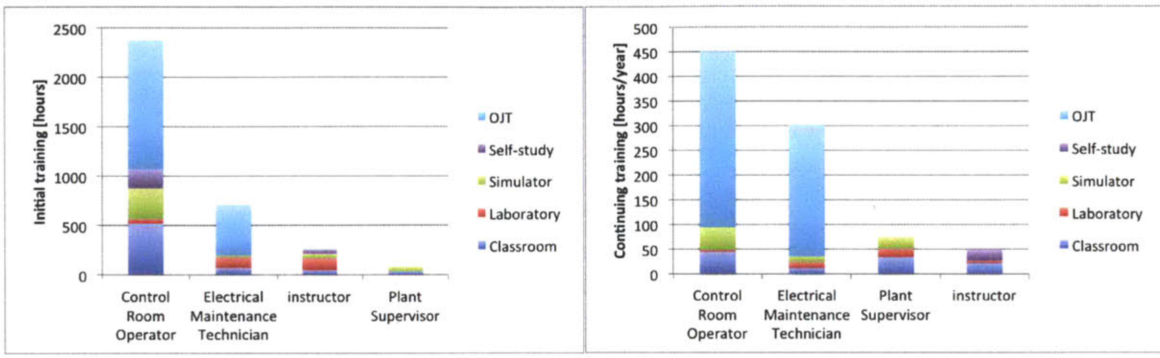
Japan

Twelve Japanese universities offer graduate or undergraduate courses in nuclear engineering. Heightened negative perceptions of nuclear energy, particularly after the accident at Chernobyl and a sodium leak at Monju, have made it difficult for nuclear engineering departments to recruit students. This has been accompanied by the worrying trend of nuclear engineering graduates joining service related industries rather than nuclear utilities and research organizations. Nuclear engineering education was restructured and nuclear engineering departments were renamed in the 1990s[7] in

[7]All but two university nuclear engineering departments have been renamed. "Quantum Energy Engineering" and "Nuclear Energy and Safety" are examples of new department names [15].

an effort to attract more students [15].

Beckjord et al. [42] explain that "[t]he approach taken by Japanese nuclear utilities to the training of operator and maintenance personnel reflects certain basic practices and attitudes found throughout the Japanese nuclear industry." As shown in Figure 3-2, a substantial portion of the initial and continuing training given to these workers is hands-on and on-the-job.



(a) Initial training

(b) Continuing training

Figure 3-2: Japan: Training plant workers [6]

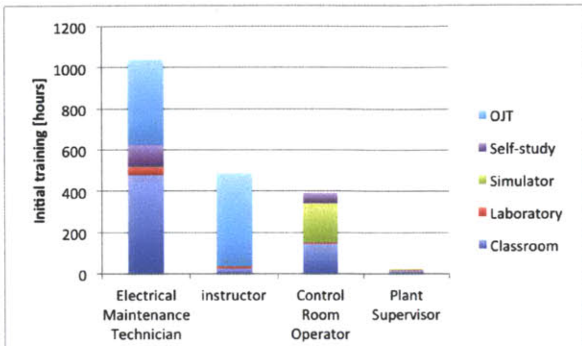
Aside from the initial wave of nuclear plant personnel who were drawn from existing power plants, Japanese utilities have hired young, inexperienced high school and college graduates and trained them on the job over periods of up to a decade. Japanese nuclear plant workers were and are trained broadly in multiple areas of plant operation and specialization is avoided. Plant operators are trained both at separate dedicated facilities for training BWR and PWR operators and also on site. Maintenance workers too receive extensive training through continuing programs that, in the past, have lasted as long as 20 years [42].

Korea

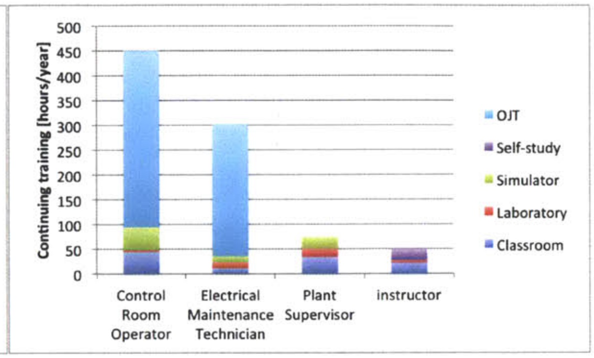
There is a strong focus on vocational training and education in Korea. Scientists and engineers are trained through university undergraduate and graduate programs. Junior technical colleges train technicians and craftsmen are trained through vocational training and education. Experienced craftsmen can undertake additional training to become technicians and engineers. Every government agency involved in nuclear energy activities also runs training centers for its employees. KAERI runs the Nuclear Education and Training Center (NTC), Korea Institute of Nuclear Safety (KINS) operates the International Nuclear Safety School (INSS), Korea Hydro and Nuclear Power (KHNP) runs the Nuclear Power Education Institute (NEPI), and finally Korea Plant Services manages the Nuclear Maintenance Training Center (NMTC). From the outset, these training centers have been established in close proximity to universities to promote collaboration and sharing of training facilities.

Plant workers are trained on-the-job for a period of 8 to 39 weeks. Interestingly in Korea, plant managers are directly both responsible for on-the-job training and evaluation of the their staff [15].

The duration and nature of training is shown in Figure 3-3.



(a) Initial training



(b) Continuing training

Figure 3-3: Korea: Training plant workers [6]

The KEPCO International Nuclear Graduate School (KINGS), unlike the institutions discussed earlier, aims to provide graduate level professional education in equal part to both international[8] and domestic students. KINGS draws its faculty from international and domestic nuclear industry and academic institutions, has an international advisory board and plans for student exchanges with several U.S. universities [43].

France, Japan and Korea have extensive systems of universities and training centers for educating and training the nuclear workforce. However, the formal structure for continuing on-the-job training that exists at Korean and Japanese utilities appears to be lacking in France.

3.7 Manpower Planning

France

The French government started making manpower forecasts by sector as part of its five year plans. These forecasts were initially extrapolations but evolved to use worker productivity and the length of the work week to determine manpower needs. Forecasted manpower needs were used to instruct schools and universities. However, disparities between actual and projected manpower needs led French planners to distrust these forecasting methods based on labour productivity and they began to defer to expert opinions. In a study mandated by the French government, the High Commissioner

[8]In 2012, KINGS expects to host up to 50 international students from the UAE, Vietnam, India, Malaysia, Indonesia, Egypt, Brazil, Turkey, Kazakhstan, Argentina, Kuwait, Philippines, Saudi Arabia, Poland , Thailand, Kenya and Qatar. We note that most of these are potential newcomer countries. As we note in subsequent chapters, the provision of training and education opportunities by the vendor country may be a decisive factor in selection of the vendor. This may be an important motivation for the establishment of KINGS.

for Atomic Energy assessed the adequacy of French educational infrastructure for supplying the next generation of scientists and engineers for the nuclear energy program. The study predicted a future shortage of workers and in response the Council for Education and Training in the Nuclear Industry was established. CFEN members include representatives of universities, EDF, AREVA, GDF Suez and sub-contractor companies and government-run research organizations. The Council aims to communicate the manpower needs of the nuclear industry to the educators and trainers and avoid a manpower shortage by coordinating their efforts. It was estimated that the French nuclear energy program will require 13,000 engineers and 10,000 technicians over the next ten years[15].

Japan

Japanese manpower needs have, since the outset, been projected through five-year development plans. It is unclear what methods are used for projecting these requirements today but in the past these projections were based on extrapolations of manpower requirements at existing nuclear plants [44].

Korea

Human resource projections for Korea's nuclear energy program are made by the Korea Atomic Energy Research Institute which has a Human Resource Development Center (HRDC). The forecasts are made by projecting sales of electricity from nuclear plants and using labour coefficients to determine the manpower needs. Using this methodology, the manpower requirements were projected up to 2030. For the nuclear power sector these human resource requirements in 2030 are 34,229 workers and 45,793 workers for the 'business as usual' and 'high' cases respectively.

Since 1995, Korea has reformulated the Comprehensive Nuclear Energy Promotion Plan (CNEPP) every five years [45]. Human resource development is a main area of focus for CNEPP. Furthermore, these plans have linked the nuclear energy and manpower planning to the goals and development of other sectors and industries.

In both France and Korea, forecasting manpower requirements and coordinating the efforts of all stakeholders in meeting the projected manpower needs has been given primary importance. Unlike in the US, explicit and long-term manpower policies exist certainly in France and Korea and probably in Japan.

While it is unlikely that American nuclear utilities will be willing to accept interventionist policies followed by the French and Korean governments for planning and meeting manpower needs, existing government agencies such as the DOE or a new institution created specifically for this purpose can coordinate training efforts and communicate manpower needs of the utilities to the trainers and educators. The communication between stakeholders that has been missing in the US has been the strength of both French and Korean nuclear energy programs.

3.8 Conclusions

This comparative study of the French, Japan and Korean manpower policies offers some insight into why utilities in different countries or under different institutional organizations of the nuclear energy program have formulated their existing manpower policies.

American utilities are cut off from research and development in nuclear energy technologies. They typically do not invest in research or communicate well with universities. Their main aim is to provide electricity reliably at the minimum possible operational cost. Uncertainty in the construction of new reactors and license renewals for existing reactors has meant that these utilities cannot and have not planned manpower needs a decade ahead like their counterparts in Korea and France. Rotation and on-the-job training programs are expensive and have long lead times for producing competent workers. The long time horizons for such programs are incompatible with the short-term goals of utilities. American utilities have therefore not invested in such programs until recently when they were started as means to attract new workers.

The inclusion of energy planning in the national development goals in France, Japan and Korea has ensured that manpower demand has been met and expected shortages have been identified in time to enforce remedial measures. Furthermore, government involvement in both research and operation of reactors has meant that while utilities in these countries do not perform research and development, the ease with which workers can be transferred from one government agency to another has allowed utilities to keep up with technological developments and breakthroughs.

There are lessons to be learned here not only for American utilities but also for utilities in emerging nuclear energy countries. Government involvement is desirable for opening channels of communication between the nuclear industry and education and training institutions. The French, Japanese and Korean experiences indicate that public acceptance measures undertaken from the outset have helped maintain a worker pipeline. Developing a manpower base before launching plant construction and phased participation of domestic manpower is a practice that worked well for both Japan and Korea and will likely be applicable to newcomer countries. Lastly, standardization of plant technology made it possible to create centralized training infrastructure for both plant operators and maintenance workers.

The following chapter reviews the manpower policies of the Chinese and Indian nuclear energy programs.

Chapter 4

Manpower Policies of the Chinese and Indian Nuclear Energy Programs

Previous chapters have examined the manpower policies of the American, French, Japanese and Korean nuclear programs. We now turn to the manpower policies of the Chinese and Indian nuclear energy programs. This chapter is organized as follows: the first section briefly describes the installed and planned nuclear capacities in India and China. Subsequent sections describe the institutional organization of the nuclear energy program in each country and the demand for and supply of manpower. An attempt is also made to deconstruct the Chinese and Indian manpower policies.

We find that there are unique manpower challenges associated with rapidly expanding installed nuclear capacity by simultaneously developing and constructing multiple reactor designs. These challenges, faced by both India and China, although of different magnitudes, are discussed in the conclusion.

4.1 Nuclear Power: status quo and future plans

India and China have installed nuclear capacities of 4385 MWe and 11,881 MWe respectively. Both countries have ambitious plans for increasing installed capacity in the future. The Chinese installed nuclear capacity is planned for an increase to 60GWe by 2020, 200 GWe by 2030 and 400GWe by 2050 [46]. In comparison, India's plans for expanding installed capacity are relatively modest. Forecasts by planners indicate that 20GWe will be brought online by 2020, 63GWe by 2032 and by 2050, 25% of the total electricity demand will be met by nuclear plants [47].

4.2 Institutional Organization

4.2.1 China

The complex organization of the Chinese nuclear energy program makes it difficult to clearly identify ownership of different entities. The National Development and Reform Commission (NDRC) and the China Atomic Energy Authority (CAEA) are the main planning and policy-making bodies. The National Nuclear Safety Administration (NNSA) is the safety regulator, China Nuclear Engineering & Construction Corporation (CNEC) is the construction company and Shanghai Nuclear Engineering Research and Design Institute (SNERDI) is one of the primary R&D organizations.

China Nuclear Energy Industry Corporation (CNNC) , and China Guangdong Nuclear Power Group (CGNPC) are the operators of the existing plants. However, China's five largest power companies - Huaneng, Huadian, Datang, China Power Investment Corporation and Guodian – will be important players in future nuclear power projects. All five companies expressed interest in constructing and operating nuclear power reactors and currently own equity in existing nuclear plants. These five companies were required to purchase equity in existing nuclear projects before constructing their own. Equity ownership in operating power plants is seen as a way for these companies to familiarize themselves with the construction, management and operation of nuclear power plants [48].

The presence of multiple power companies and utilities makes the Chinese nuclear industry much more horizontally disaggregated than the one in India. However, these power companies have equity ownership in each others' projects. Quantifying the impact of horizontal disaggregation of utilities but with utilities having equity ownership in each others' projects on learning rates would be an interesting exercise.

4.2.2 India

The Indian nuclear energy program is characterized by a high degree of both horizontal and vertical aggregation. The Atomic Energy Commission (AEC) is the central planning body for the nuclear energy program. The Atomic Energy Regulatory Board (AERB) and the Department of Atomic Energy (DAE) fall under the purview of the AEC. The former is the safety regulatory body while the subsidiaries of the latter carry out R&D, reactor construction and operation, and fuel cycle activities. BHAVINI, Nuclear Power Corporation of India Limited (NPCIL), Uranium Corporation of India Limited (UCIL) and the Nuclear Fuel Complex are the subsidiaries of the the DAE. Of these, BHAVINI and NPCIL play multiple roles. They are the designers, architect and engineers, and operators of fast breeder and light water reactors respectively. Bhabha Atomic Research Center (BARC) , Indira Gandhi Center for Atomic Research (IGCAR) and Board of Radiation and Isotope Technology (BRIT) are the research and development organizations.

Figure 4-1 shows the organization of the Indian nuclear energy program.

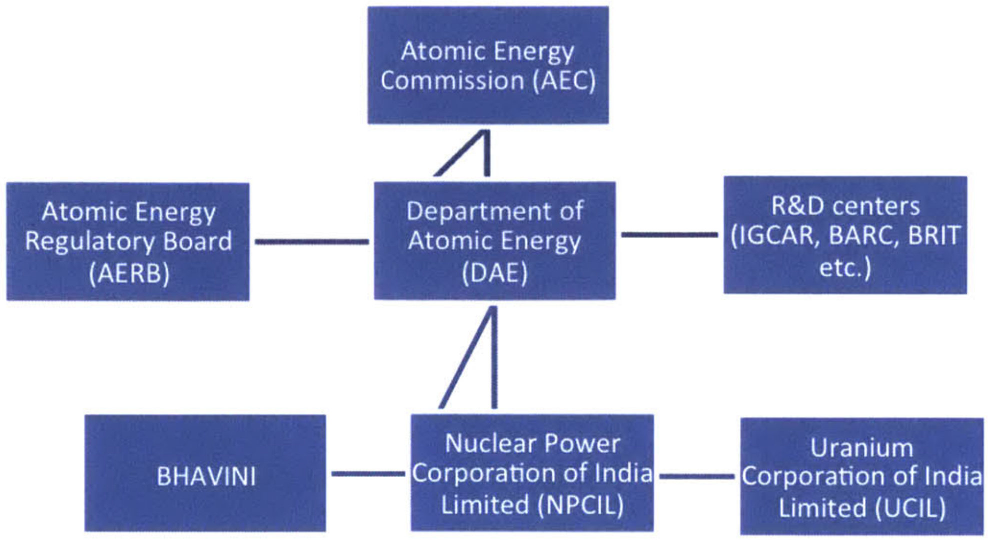


Figure 4-1: Institutional Organization of the Indian Nuclear Energy Program

Public utilities such as the National Thermal Power Corporation (NTPC) and the Indian Railways, neither of which currently have a presence in the nuclear industry, have expressed interest in building nuclear plants. The current institutional organization of the nuclear industry will possibly evolve to include these organizations.

4.3 Demand: Manpower needs of a growing nuclear energy program

4.3.1 China

China plans on increasing its installed nuclear capacity to 60 GWe by 2020, 200 GWe by 2030 and 400 GWe by 2050. These numbers for installed capacity roughly correspond to a nuclear workforce of 48,000 by 2020, 160,000 by 2030 and 320,000 by 2050 for reactor operation and maintenance alone.[1] Table shows a breakdown of 2020 workforce requirements for China and India. [2]

Table 4.1: China and India : Estimated Nuclear Workforce Requirements by 2020. The projected installed capacities for China and India by 2020 are 60GWe and 20 GWe respectively.

Occupation	Staff/MWe for a US plant [8]	Workers needed by 2020	
		China	India
Nuclear Engineers	0.025	1500	500
Civil engineer	0.005	300	100
Computer, electrical and I&C engineers	0.02	1200	400
Mechanical engineers	0.015	900	300
Project / Plant engineers	0.03	1800	600
Chemistry Technicians	0.02	1200	400
Maintenance technicians*	0.135	8100	2700
Radiation protection & rad waste handling technicians	0.035	2100	700
Security personnel	0.07	4200	1400
Trainers	0.035	2100	700

*Includes I&C technicians, mechanics

4.3.2 India

The Indian installed nuclear capacity is planned for an increase to 20 GWe by 2020 and 63 GWe by 2032. Subsequently, the installed nuclear capacity is envisaged to increase by 2050 to meet 25% of the country's electricity demand. Using the simple methodology of multiplying the installed capacity by average staffing, we find that India will need a nuclear workforce of 16,000 by 2020 and 50,400 by 2032. The breakdown by occupation for the 2020 workforce is shown in Table 4.1. Although these manpower needs are modest compared to those of China's, they must be evaluated in the context of education and training infrastructure available to train the future workforce.

4.4 Supply: Meeting the Manpower Needs

The safe and efficient operation of nuclear plants is as much dependent on the proficiency of nuclear plant workers as it is on the robustness of the equipment that comprises nuclear plants. The education and training infrastructure in both China and India is assessed to evaluate whether it is up to the task of supplying the requisite manpower.

[1] These estimates are based on a levelized staffing of 0.8 staff/MWe. These values for levelized staffing were seen to be consistent for French and US single-unit plants. However, planned nuclear projects in China are likely to be comprised of multi-unit plants with multiple units at a site. China therefore stands to benefit from staffing economies and the actual staffing requirements may be slightly lower than the ones estimated above.

[2] The occupational composition of the Chinese and Indian nuclear workforces was not available at the time of writing and the occupational composition seen at US plants, as shown in Table 2.1 , was used to obtain a reasonable estimate. Workers reported as 'all other workers' in Table 2.1 are not shown in this calculation.

4.4.1 China

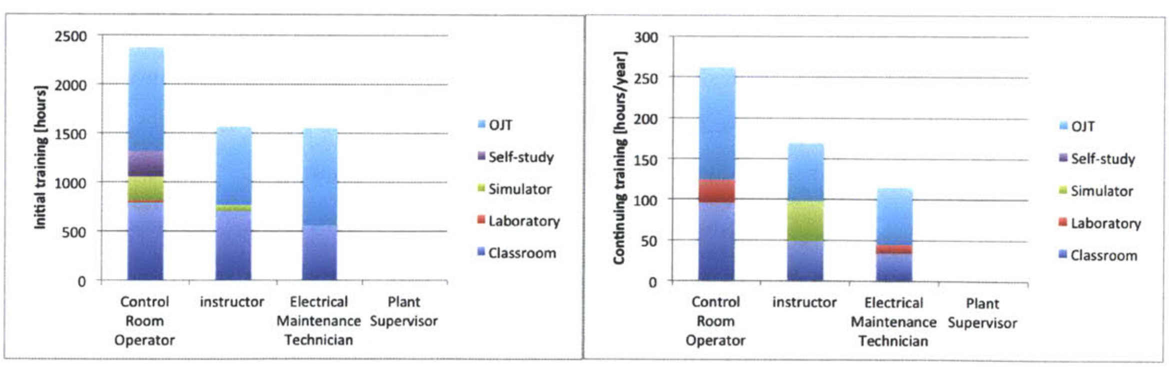
Nuclear engineering courses are offered in China at both the undergraduate and graduate level. University nuclear engineering programs have been set up to meet the growing demand for nuclear scientists and engineers. In 2000, 6 universities offered nuclear engineering programs at the undergraduate level. This number has increased today to 37. A total of 47 universities offer graduate nuclear engineering programs.

Although the number of university nuclear engineering programs has increased in response to the growing workforce needs of the expanding installed nuclear capacity, there exists a problem of quality control. A lack of experimental facilities, textbooks and faculty is a major cause for concern. Future efforts will need to be directed as much towards expanding training and education infrastructure as they are towards improving the quality of existing programs [49].

Besides domestic infrastructure for training and education, both classroom and on-the-job training and education opportunities provided by reactor vendors such as AREVA and Westinghouse have played and will continue to play an important role in producing a competent workforce .

Workers for the Daya Bay plant were trained by visiting French scientists and engineers. This training was complemented by sending Chinese trainees to France. Nine Chinese delegations made 48 trips to France and 8 French delegations made 28 trips to China. This exchange of personnel showed that training was most effective when it was given on the job by integrating Chinese trainees into host teams at French nuclear plants [41].

Figure 4-2 shows the duration and type of training giving to plant workers at the Daya Bay and Qinshan plants.



(a) Initial training

(b) Continuing training

Figure 4-2: China : Training plant workers [6]

Similar arrangements have been made with Westinghouse and Shaw for reactors under construction. Chinese nuclear engineering graduates were sent to Pittsburgh for training in reactor design by Westinghouse engineers and have returned to join SNERDI. Westinghouse and Shaw engineers manage construction workers and train them on-site as the need arises [48].

4.4.2 India

Nuclear engineering is not offered as a major course of study at the undergraduate level in Indian universities. Currently, four universities - IIT-Bombay, University of Delhi, Jadhavpur University and the Homi Bhabha Nuclear Institute (HBNI) offer graduate programs in nuclear science and engineering. HBNI's graduate programs are taught at the 10 principal R&D centers of the DAE. Several of these R&D centers, also known as the Constituent Institutions (CIs) offer one and two year diploma courses for radiation physics technicians.

In addition to the above, the skilled manpower needs of the Indian nuclear energy program are met through the recruitment of science and engineering graduates by the BARC training school. The training school recruits 300 graduates annually with plans to expand its training infrastructure in the near future. Such an expansion will be necessary to meet the manpower needs of a manifold increase in installed nuclear capacity. All R&D organizations, utilities and universities are owned and controlled by the government. Centralized planning and execution of nuclear energy policy has, to date, resulted in a manpower supply that is adequate for meeting demand.

However, an increase in installed nuclear capacity from roughly 4000 MWe today to 20 GWe by 2020 will require that the number of nuclear plant workers alone increases from 3,200 to 16,000. Even in the absence of attrition of the existing nuclear plant workers, the DAE and its subsidiaries will need to hire and train close to 1600 new workers annually. Not all of these will be scientists and engineers. However, it is clear that approximately a five-fold increase in existing training and education infrastructure will be needed to meet the manpower requirements for 2020.

New training infrastructure will be needed to train plant workers for indigenous reactor designs. However, much of the nuclear capacity installed by 2020 will be light water reactors built by Areva, Westinghouse and Rosatom. Contracts with all three vendors include agreements for training plant workers. India has, in the past, sent scientists and engineers to Russia for training and education. Some of the increase in the training infrastructure will be local and it is likely that the rest will be met through education and training agreements with foreign reactor vendors.

4.5 Making sense of the Chinese and Indian Strategies

Both China and India have chosen technology and reactor deployment trajectories vastly different from those adopted by the countries studied earlier in this work. Both countries are soliciting multiple reactor vendors while simultaneously augmenting domestic research and development capabilities. India's strategy seems to be driven in part by its three-stage nuclear energy program that seeks to exploit domestic thorium reserves. However, this alone does not explain India's willingness to build light water reactors from several different vendors. China is attempting to rapidly transform its nuclear energy program from an importer to an exporter of reactor technologies.

A 2011 State Council Research Office report notes that China should not over-invest in Generation-II and III reactors that would still be in operation in 50 years when several nuclear energy programs might already have made the move to Generation IV technology [46]. This suggests that China's experimentation with multiple reactor designs may be driven by a desire to keep abreast of and lead technological developments.

It is possible that both countries are soliciting multiple reactor vendors as a means to lower costs through more favorable contracts, encourage efficiency and acquire project management and technology simultaneously from multiple vendors countries and transfer them to domestic entities.

Specialization and the 'Seeding' Phenomenon

Plants in both countries are operated, managed and maintained by relatively high skilled workers, many of whom have university degrees. There are three possible reasons for higher educational qualifications and lower levels of specialization at Chinese and Indian plants.

First, high-skilled workers at these plants are likely to be better able than low-skilled workers to transfer knowledge of operations to designers and scientists at R&D organizations such as BARC and SNERDI. Relatively easy flows of workers , and therefore information, between plants and R&D organizations probably accelerates iterations over reactor designs and localization of technology.

Second, high-skilled workers at the early plants may be used to 'seed' future plants. China pursued this strategy by employing highly qualified workers. University level engineering educations were pre-requisites for the majority of posts at the Daya Bay plant [6]. The Daya Bay workers were trained both on-site by French engineers and also in France at the reference plants. These high-skilled workers then trained workers for subsequent CGNPC plants. This planned attrition or 'dilution' of competence at the Daya Bay allowed newer plants to be 'seeded' with competent workers [50, 51]. This phenomenon is not entirely novel to nuclear industries. In the early years of the U.S. nuclear program , utilities also rigorously trained a few workers who then trained their co-workers at new reactor units at the same plant. This 'seeding' phenomenon was used by US utilities to reduce reliance on the vendors and AEC institutions for training and appears to also have been used by China for, over time, reducing reliance on the vendor country, which for the Daya Bay plant was France.

Finally there is a third factor that favors low initial specialization and high educational qualifications. We have reason to believe that workers with high educational qualifications are needed at the outset to successfully receive codified and tacit knowledge from the vendor country for rapid technology transfer. This subject is treated more thoroughly in Chapter 7.

The three explanations offered here are not inconsistent with each other. Further, all of this suggests that there is something about the projected scale of the nuclear energy programs and a desire for self-sufficiency in both countries that causes India and China to proceed as they have.

However, as was hinted at the outset of the chapter, both countries face non-trivial manpower development challenges, to the discussion of which we now turn.

4.6 Concluding Remarks on Workforce Development Challenges and Options

The US, France, Japan and Korea have reached relative steady states in terms of installed nuclear capacity. These older and more mature nuclear programs face challenges of an aging workforce and knowledge management. The manpower challenges that India and China will confront in rapidly constructing and bringing reactors online over the next several decades are unique.

Both countries plan on building reactors from international vendors while simultaneously developing indigenous reactor technology. As a result, neither country is likely to benefit from the economies and learning associated with standardization. A continuous increase in installed capacity will require that the nuclear workforce in both China and India grows in proportion to the increasing manpower needs of the new nuclear plants, R&D organizations and regulatory bodies. Furthermore, the diversity of reactors being built has several implications for workforce development.

First, the diversity of reactor designs will preclude the use of a single central facility for training plant workers. For example in India, BARC currently trains plant workers at its training schools. However, as the newer plants designed by Areva and Rosatom are brought online along with indigenous FBR designs, it is likely that training will be decentralized.

Second, diversity of reactors will require investments in simulators for each reactor type. Instructors and trainers proficient with each reactor design will have to be recruited or trained.

Third, a lack of standardization is likely to hinder mobility of labour in the nuclear industry. The expertise of workers at a particular plant will not be directly applicable to plants based on different reactor designs. Limiting labour mobility could slow down inter-plant learning.

Finally, the presence of multiple utilities and reactor designs will mean that the regulators will be have to rapidly gain experience in licensing and regulating multiple reactor designs.

Although the magnitude of installed and planned nuclear capacity in China is greater than that in India by almost an order of magnitude, the Chinese and Indian approaches towards workforce development have been similar. The focus is on building new nuclear plants with the implicit assumption that the demand for manpower will be met through a combination of domestic education and training infrastructure, and training agreements with reactor vendors.

This 'build first' policy implicitly followed by both China and India is different from the 'education first' policy adopted by France, Japan and Korea. At least for China's case, the success of this 'build first' policy is contingent on the success of the seeding phenomenon discussed earlier.

The smaller projected scale and slower pace of development of the Korean program made the 'education first' policy a feasible choice. However, for programs with larger projected scale and pace of development, that China is currently experiencing and to which India aspires, the 'build-first' policy in conjunction with 'seeding' may be needed for rapidly adding installed capacity while reducing dependence on the vendor country.

These national attitudes towards educating and training a nuclear workforce are perhaps byproducts of practices in related industrial sectors or the country as a whole. For example, a scarcity of natural resources in Korea along with a small landmass and high population density resulted in the Koreans viewing their manpower as a primary resource that was industriously developed, often in excess of what was needed [52].

China and India, despite being the most and second-most populous countries have significantly larger landmasses and a relative abundance of natural resources. As a result, the national focus in each country is as much on exploiting these resources as it is on exploiting manpower. For example, the abundance of thorium resources in India is a primary reason for the three-stage nature of the nuclear energy program.

If China and India do go ahead with planned expansion of nuclear capacity, both the quantity and quality of education and training resources will need to increase in proportion to the installed nuclear capacity.

Chapter 5

Cross-National Differences in Manpower Policies

Introduction

Studies of the American, French, Korean, Japanese, Indian and Chinese nuclear energy programs highlight differences in their respective manpower policies. Manpower policies at US nuclear plants have been characteristically myopic and little attention has been paid to future manpower needs. The focus has been on reducing costs through aggressive specialization of operation and maintenance tasks. In France, Japan and Korea decade-long projections of manpower needs are made. Plant workers have been educated and trained well before plant construction. On-the-job training of personnel in all three countries can take as long as, and in some cases longer than, a decade. In China and India, it appears that manpower supply is barely meeting demand. Furthermore, there are concerns about the quality of education and training programs.

This chapter uses data from the IAEA world survey on nuclear power plant personnel training [6] to demonstrate cross-national differences in training practices. Following this, an attempt is made to explain national differences in training times and methodologies, staffing levels and extent of manpower planning. Historical factors, structure of the industry, safety and economic regulatory influences and future expectations are presented as the four main factors that have affected and continue to affect the manner in which nuclear plants manage their workforces.

This chapter concludes with remarks on why companies in general and nuclear plants in particular would want to invest in training their workforce. Preliminary assessments on what this means for new nuclear energy programs are also put forth and developed further in the next chapter.

5.1 Cross-national differences in training

The IAEA world survey on nuclear power plant personnel training contains data on twelve different types of nuclear plant workers including management, control room operating staff, various technicians and instructors. Here, we present the training data for Plant Supervisors, Control Room Operators, Electrical Maintenance Technicians [1] and Instructors in China, France, Japan, Korea and the US. [2]

A word of caution on the survey data presented here is in order at the outset. The IAEA survey was published in 1999. We expect that there have been changes in training methodologies in the last decade. However, we do not expect that these changes have been significant enough to render all of this data obsolete.

Following the TMI accident in 1979, NRC mandated and INPO recommended changes in plant training and staffing which came into force by the late 1980s. It is therefore expected that the data published in the IAEA survey reflects these post-TMI changes. The French and Japanese nuclear energy programs experienced rapid expansion of installed nuclear capacity and reached relatively steady states by the mid 1990s.[3]

At the time of the survey, only two Chinese nuclear plants, the Qinshan and Daya Bay plants, were in commercial operation. Data on the training of Chinese nuclear plant workers comes from these two plants alone. Similarly, the Korean nuclear fleet is comprised of 21 nuclear plants. Eleven of these plants came online post 1995. It is expected that the Chinese and Korean training times and methodologies have undergone significant changes with the expansion of installed nuclear capacities.

Nevertheless, the data presented here are useful for comparing national differences in training times and practices.

5.1.1 Educational Qualifications

The required educational qualifications for plant workers of interest are shown in Table 5.1. These qualifications are highest for Chinese plant workers and lowest for American and Japanese workers. The educational qualifications for French and Korean workers are intermediate. The nuclear energy programs of all five countries are predominantly based on LWR technology that was initially developed in the US. The Chinese nuclear energy program is in a sense the youngest of the five.

The differences in required educational qualifications of the plant workers could be the result of regulatory practices. Another possible reason is a shift in occupational composition from scientists

[1] The survey contains data for training given to the following types of technicians: Electrical maintenance, mechanical maintenance, Radiation Protection and Chemistry. It was found that the training given to the different maintenance workers was roughly of equal durations. Therefore, only the data for Electrical Maintenance workers is presented here.

[2] The survey does not include training data for Indian nuclear plant workers

[3] The French and Japanese reactor fleet are comprised of 58 and 51 reactors respectively. The IAEA survey was designed and conducted in 1995. Four new French reactors and seven new Japanese reactors entered commercial operation post 1995.

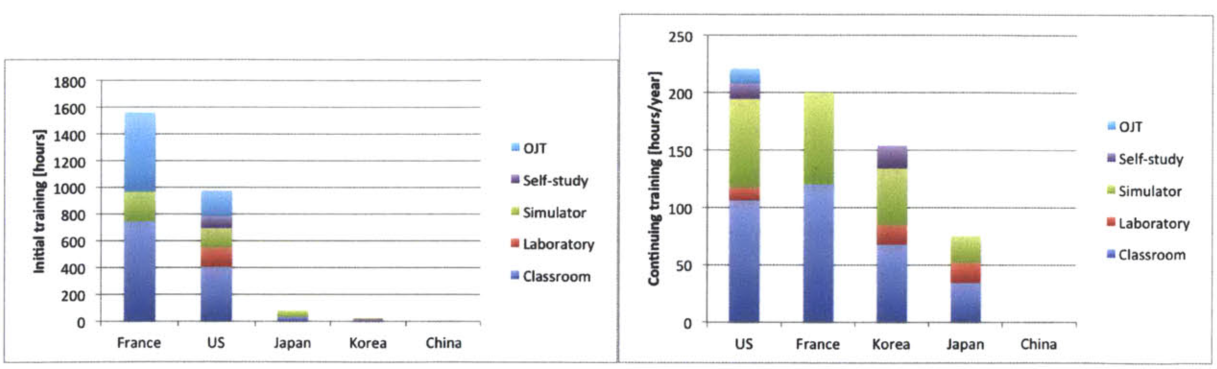
and engineers to technicians over time due to increasing specialization. The US nuclear utilities derived their operating and training practices from the older coal plants that used specialized operating procedures. Nuclear plants too, over time, reduced O&M costs by specializing tasks. The low educational qualifications required of American plant workers are possibly the result of specialization of complex procedures into simpler tasks. However, Japanese nuclear plants have deliberately avoided specialization of tasks. Thus, the previous proposition alone does not explain why Japanese plant workers, who perform more complex tasks, are only required to have secondary school diplomas. Explaining this apparent discrepancy requires that we examine training times and methods for plant workers in these countries.

Table 5.1: Educational qualifications of plant workers. [GE = graduate engineer or diploma engineer degree (4-6 years university study); E = engineering degree (2-3 years university study); TS = technical school diploma; SS = secondary school diploma] [6]

Plant Worker/Country	China	France	Japan	Korea	USA
Plant Supervisor	GE	GE	SS	GE/E	SS
Control Room Operator	GE/E	E/TS	SS	E/TS	SS
Electrical Maintenance Technician	GE/E/TS	GE/E/TS	SS	E/TS	SS
Simulator Instructor	GE	GE	-	GE/E	SS

5.1.2 Plant Supervisor

As shown in Figure 5-1 , plant supervisors in Korea, Japan and China receive very little or no formal initial training. Initial training times for plant supervisors are longest in France and a significant portion of it is on-the-job training (OJT). Plant supervisors at French plants select and train their understudies. In contrast, most of the initial training given to US plant supervisors is in a classroom setting.



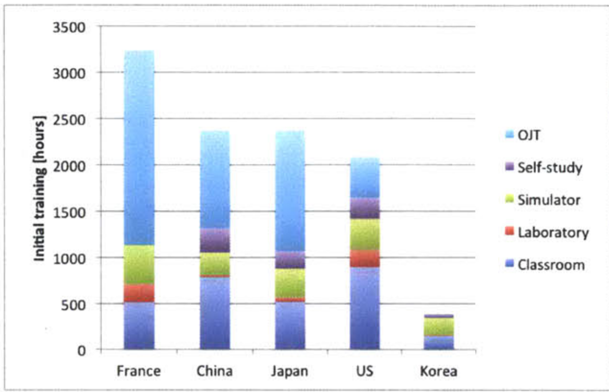
(a) Plant Supervisor Initial Training

(b) Plant Supervisor Continuing Training

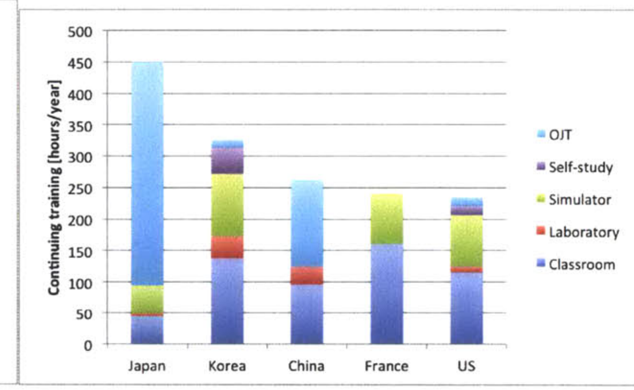
Figure 5-1: Plant Supervisor training [6]

5.1.3 Control Room Operator

Initial training times for control room operators are the longest in France. A significant portion of the initial training given to control room operators in France, Japan and China is on-the-job. Conversely, both the US and Korea use very little OJT and rely heavily on classroom training. In Japan, more than three fourths of the continuing education of reactor operators is OJT.



(a) Control room operator initial training

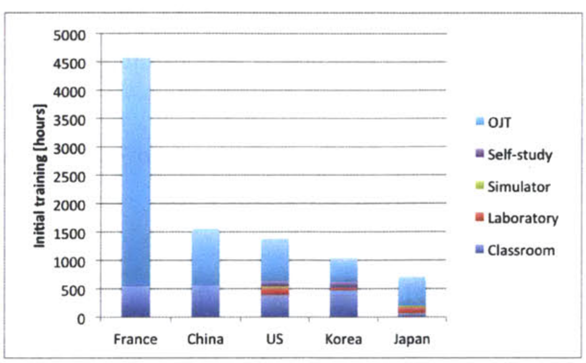


(b) Control room operator continuing training

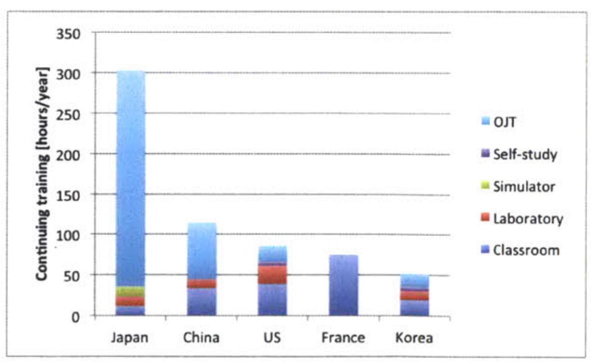
Figure 5-2: Control room operator training [6]

5.1.4 Electrical Maintenance Technician

In all five countries, training of Electrical Maintenance Technicians is primarily on-the-job. This could be due to high costs associated with building equipment mock-ups for training technicians and also insufficient documentation of maintenance procedures. Once again, the duration of continuing training is longest for Japanese workers.



(a) Electrical Maintenance Technician initial training

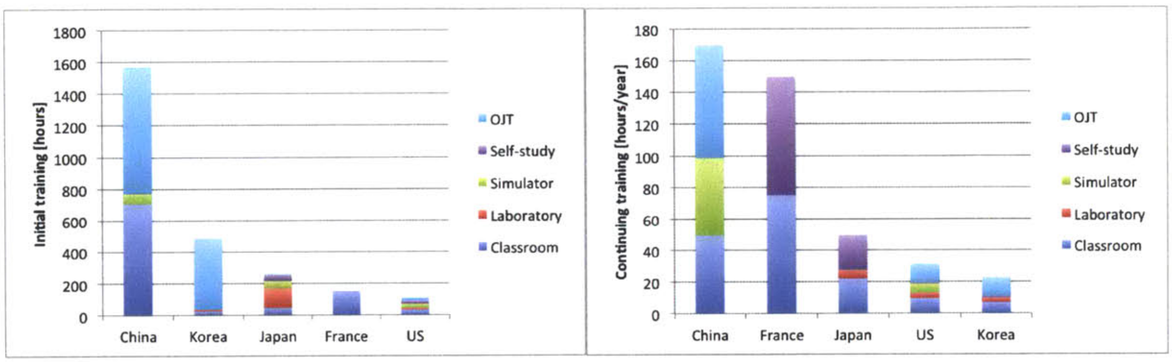


(b) Electrical Maintenance Technician continuing training

Figure 5-3: Electrical Maintenance Technician training [6]

5.1.5 Instructor

Experienced plant personnel often play the role of instructors who train plant workers in a classroom setting or by the use of simulators. A new nuclear energy program is unlikely to have an existing base of experienced plant workers. As a result, it becomes necessary to train the instructors themselves. We see this trend in Figure 5-4. Durations of both initial and continuing training are longest in China. Not surprisingly, the duration of initial instructor training corresponds to the size or age of the nuclear energy program.



(a) Instructor initial training

(b) Instructor continuing training

Figure 5-4: Instructor training [6]

We observed that the required educational qualifications were lowest for American and Japanese workers. However, plant operating procedures in Japan are much less specialized than in the US. Yet Japanese workers whose educational qualifications are equivalent to their American counterparts are able to perform more complex tasks. We attribute this to the extensive OJT, both initial and continuing, given to all Japanese plant workers.[4] Conversely, a significant portion of training in the US is hands-off and done through classroom courses or self-study. Additionally, it was also observed that on average initial training times for plant workers are longest in France while continuing training times are on average longest in Japan.

Having identified national differences in training strategies, we now step back to explain the observed cross-national differences in manpower policies.

5.1.6 The Impact of Simulators on Training [1]

We pause here to briefly describe the impact of simulators on training nuclear plant workers. Development of simulator technology has likely created differences over time rather than cross-national differences in training. Prior to the TMI accident in 1979 few plants had on-site simulators for training workers. Further, simulators at the time were usually located at centralized facilities far

[4]Another reason could be the greater effectiveness of the Japanese secondary school system.

from the plants themselves. The layout and designs of these older simulators were not identical to those of the plant control rooms that they were intended to simulate. Additionally, these simulators lacked the ability to simulate two-phase flow conditions associated with accidents. Training times using simulators were limited to a week or two a year and the trainers themselves were not familiar with the operating experiences of the plants whose workers they were training.

Advances in simulator technology have made it possible for nearly all plants to have full scope simulators on site that are used for training and examination purposes. An increase in the accessibility of simulators has meant that simulators are used not only to train reactor operators but also maintenance workers, who, as a result, have a better understanding of how their work impacts plant performance.

An additional consequence of the use of simulators has been the decentralization of training activities. This effect has been pronounced in France and Russia which have shifted from a few simulator-equipped centralized training centers to training facilities at each plant. In the U.S., too, the Tennessee Valley Authority (TVA) has moved its simulators from a central location to individual plants.

The above discussion suggests that increased use of simulators has improved the quality of training. Although it is clear that a positive correlation exists, aggregate indicators of plant performance such as capacity factors make it difficult to isolate the the impact of simulator usage on plant performance and safety.

5.2 Reasons for Cross-National Differences in Manpower Policies

5.2.1 Historical factors

In the US, the first nuclear reactors to be built were operated by utilities that already owned coal plants. Such utilities had, over time, learned to control operating costs by the breakdown of complex operating procedures into simpler tasks that were assigned to technicians and craftsmen rather than scientists and engineers [13]. The apparent success of these methods made these utilities averse to change. It is possible that these utilities discounted the possibility of their own workers discovering labour-saving and cost-reducing operating techniques. Utilities therefore did not spend signifiant amounts of time or money on training personnel. All of the above seem to indicate that utilities viewed their workers as disposable resources rather than as assets to be developed through extensive training and education. American utilities assumed that their existing operating practices would easily be adapted for operating nuclear plants. The workforce management of today's utilities is at least in part explained by the practices adopted by their predecessors.

Conversely, utilities in France, Japan and Korea were much less reluctant to invest in training and educating their workers. On average, initial and continuing training times are longer in all three countries. French, Japanese and Korean planners closely followed nuclear plant construction and operation in the US before embarking on their own nuclear energy programs. They were no doubt able to learn from the experience of American utilities.

While American line managers opined that training was a drain on financial resources, their French, Japanese and Korean counterparts paid more attention to training workers. Managers at French nuclear plants reported spending equal amounts of time on operating and training workers in the initial years of plant operation [39]. At Japanese nuclear plants, inexperienced high school graduates were hired and received on-the-job training for up to a decade.

In contrast to American plants where specialization was the norm, Japanese utilities systematically avoided specialization of worker skills and trained their workers broadly [42]. This practice was adopted by Korean plants whose organization was modeled after Japanese ones. In Korea, managers were directly responsible for the education and training of their subordinates [41].

There are also some indications that plants in Japan, France and Korea have been more open to incorporating changes suggested by their workers [6]. It appears that, unlike American utilities, utilities in these three countries were investing as much in their manpower as they were in the equipment that constituted their plants.

The manpower policies that were adopted at the first nuclear plants to be constructed were propagated to plants that were brought online in subsequent decades.

5.2.2 Structure of the Industry

It is conjectured here that the structure of the US nuclear industry has influenced manpower policies at the utility and plant level.

Until the late 1990s the ownership of U.S. nuclear plants was fragmented. Most regulated utilities operated at most two nuclear plants. Furthermore, these plants at most had two reactor units. However, beginning in the late 1990s the deregulation of electricity markets in several states was accompanied by a consolidation of nuclear plant ownership. Plants having high production costs that would otherwise have been unable to compete in deregulated electricity markets were purchased by independent power producers. In this manner almost half of the nuclear reactors in the US were divested and today, ten companies own more than 70% of the installed capacity [53].

Fragmented ownership of nuclear plants had resulted in heterogeneity in plant designs across the industry [54] and as a result, diversity in staffing and operating procedures. The training times shown in figures presented earlier in this chapter are averaged across nuclear plants in the US. Several plants have training times much lower or higher than the averages shown in the earlier figures.

Utilities that owned single plants were unable to realize staffing economies and for several tasks found it less expensive to employ contractors rather than full time employees. Aside from permanent onsite facilities for training reactor operators, training given to technicians and craftsmen was through temporary programs that were set up on site shortly before plant construction and dismantled once operation began [13].

Consolidation of the US nuclear industry affected manpower policies. Companies that owned multiple plants were able to amortize staffing and training expenses across several plants and reduce use of contractors. This was accompanied by an increasing focus on planning future manpower needs. As an example, Entergy uses systems dynamics tools to estimate future workforce requirements and its recruitment is informed by these studies. Finally, the horizontal aggregation of the industry also produced manpower economies. Data on plant staffing shows that companies that own multiple plants benefit from lower levelized staffing. This can be attributed to reductions in staffing at individual plants by centralizing work common to all plants and also to the dissemination of labour-saving practices to plants that were previously inefficiently managed.

The consolidated structure of the nuclear industries in France, Japan[5] and Korea influenced workforce management. All three countries have central facilities for training reactor operators and maintenance workers [41, 15, 55]. The larger size of the utilities also necessitates long-term manpower planning. All plants in France, Japan and Korea have multiple reactors with as many as six reactors at a single plant. Not surprisingly, these large plants benefit from even greater staffing economies than US plants. Although current staffing data is not available for Japanese and Korean plants, levelized staffing at French nuclear plants is lower than at American plants.

The duration of on-the-job training programs in all three countries indicates a greater willingness to train workers. This willingness can be attributed to the structure of the industry. In France and Korea, nuclear plants are operated by a single utility. This limits mobility of workers whose knowledge is specialized. Neither French nor Korean utilities need worry about losing their workers to domestic competitors and low turnover rates may have have made these utilities less reluctant to educate and train workers than their American counterparts.

The structure of the growing Chinese nuclear industry resembles that of the US. Although CNNC and CGNPC operate the existing commercial plants, the five major Chinese power companies will be key players in planned nuclear plant projects. This trend of horizontal disaggregation is likely to produce a diversity of training times and methodologies across the industry. Conversely, the high level of both horizontal and vertical integration of the Indian nuclear industry is likely to result in training practices similar to those of France or Korea.

[5]The extent of consolidation is much less in Japan where ten different utilities own and operate nuclear plants. However, each utility exclusively operates either PWRs or BWRs. Furthermore, the two largest utilities , TEPCO and Kansai account for the majority of the installed nuclear capacity. Therefore, while French and Korean nuclear industries represent one end of the spectrum where all nuclear plants are operated by a single utility, the Japanese nuclear industry does represent a level of consolidation greater than the US.

5.2.3 Economic and Safety Regulatory Pressures

A third set of factors that affect training and staffing are economic and safety regulatory pressures. These are discussed simultaneously in the interest of comparing their conflicting influences.

Almost half the nuclear plants in the US have been divested but the remainder are operated by regulated utilities. The rates paid to these utilities are meant to cover fixed and recurring costs. Economic regulators have allowed increases in operating costs resulting from NRC regulations to be passed on to the ratepayers but have been less receptive to passing on costs resulting from plant-initiated changes [54].

Such rate-setting does very little to promote efficient plant operation. However, in some states greater efficiency in plant operation has been incentivized by setting the rates over an extended period of time and allowing the utility to collect any profits it makes as a result of improvement in operation techniques [53].

In this environment utilities have reaped profits by minimizing operational costs. Such reductions have been made possible by a combination of reducing training and staffing and hiring contractors. The behavior of regulated utilities indicates that they respond to economic incentives as quickly as possible by modifying existing practices rather than investing in training and educating their personnel for developing new operating procedures. The tried and tested method of cutting costs by reducing staffing has worked in the past whereas the utilities are unfamiliar with research and training as a means to reduce costs and likely see both activities as being risky.

Plants that produce electricity for competitive markets however are not given economic incentives in the form of fixed rates to which they must respond. Instead, they must create opportunities for making profits and this necessitates long term planning and personnel training.

Therefore, we conjecture here that an absence of competitive electricity markets and use of long term power purchase agreements in fact makes nuclear utilities more myopic and averse to investing in long-term manpower training or planning. The risk associated with future changes to economic incentives[6] further aggravates the situation.

Safety regulatory pressures have an opposing effect on plant staffing. Economic pressures tend to reduce staffing but safety regulatory pressures tend to increase it. This became evident especially following the TMI accident. Post-TMI NRC regulations fixed control room staffing levels. NRC requirements and INPO recommendations for additional testing requirements were also instituted. Both NRC and INPO actions appear to have similar influences on plant staffing levels - that is to say they tend to increase them [22]. If utilities fail to comply with NRC regulations, they can be forced to shut down plants or pay fines on the order of millions of dollars. Failure to comply with INPO recommendations on the other hand increases insurance premiums.

[6]As an example, in 1998 the California Public Utility Commission (PUC) fixed a price that the Diablo Canyon Nuclear Plant would receive for every kilowatt hour of electricity for the next ten years. However, six years later, the PUC reversed its decision and reduced the price [53].

Plants were forced to respond speedily to new NRC regulations that necessitated raising the worker competence to perform additional tasks. This was accomplished by hiring new workers rather than retraining existing ones.

The NRC also exerts its influence by accrediting training programs at nuclear plants. Interestingly, nuclear plant staffing studies show that operation and training staffing levels exhibit the smallest ranges across the US nuclear industry. This indicates that the NRC can play a significant role in standardizing nuclear plant staffing levels across the industry.

Conversely, in France, Japan, Korea, China and India the economic and safety regulators' relations with utilities are cooperative rather than adversarial and regulators consult with plants before recommending changes. Safety regulatory authorities do not mandate staffing levels or provide short-lived economic incentives. Utilities in these countries operate in a safety and economic regulatory environment that is less susceptible to change than in the US. It is possible that this stability contributes to the ability of utilities in all three countries to follow longer term manpower policies.

5.2.4 Future Expectations

It is also proposed here that future expectations of the nuclear industry influence manpower policies. In the US, economic uncertainties relating to electricity tariffs and safety regulatory uncertainties relating to new build or life extensions may disincentivize training.

The nuclear energy programs of France, Japan, Korea, China and India are part of the larger plans for national development. As mentioned earlier, plants in these countries also face fewer economic and safety regulatory uncertainties. This increases the utilities' willingness to train workers despite long lead times.

5.3 Conclusions

An important question to address is whether the conditions in the electric power sector in general and specifically at nuclear plants are in fact conducive to training. Answering this question requires first answering another: why would companies want to invest in training their employees? Training results in productivity increases, make employees more self-sufficient and enables the firm to rapidly incorporate new technologies. Training also improves safety and reduces employee turnover rates [56, 57].

First, as discussed earlier, regulated utilities do not have sufficient incentive to invest in training their workers to benefit from learning effects. In fact, the literature seems to suggest that that the reverse is true. Downward adjustment of electricity rates might be sufficient incentive for firms to deliberately keep costs high [58], slow down learning or not take any measures to speed it up.

Second, power plants are highly structured hierarchies. Workers perform periodic and fixed tasks under close supervision. This would suggest that self-sufficiency is in fact not desirable.

Third, the long lifetimes of power plant equipment mean that new technology is taken up incrementally if at all. Therefore, the long product cycles of equipment shelter power plants from having to keep up with technological change. Regulated utilities do not face competition and divested plants do not need to adapt to or incorporate new technologies to stay competitive.

Fourth, at least in the US, the widely held view seems to be that plant operation will be safe and accidents will be avoided as long as safety regulations are complied with. This is less true in France and Korea where utility-regulator relations are cooperative rather than hostile and plants themselves initiate changes to ensure safety. We have already discussed that economic regulators in the US are not receptive to plant-initiated changes and any measures to improve safety usually come from the NRC rather than from nuclear plants themselves.

All of the above suggests that conditions in which nuclear plants operate are not suitable for investments in training. There are obvious benefits of training workers and some of these were presented earlier. Countries such as China and India that are expanding existing nuclear energy programs and countries about to embark on new nuclear energy programs should consider what implicit or explicit impacts regulatory measures, industrial structure, historical precedents and future expectations are likely to have on the competency of their nuclear workforce.

Newcomer countries could also benefit from comparing workforce management at regulated utilities and divested plants. Do utilities or companies that operate multiple plants rotate workers from site to site? How do staffing levels at regulated plants compare with those at similar merchant plants? What are the qualifications of new employees? What are the costs of training and time scales for recovering these costs? Answering these questions will help a newcomer country make informed decisions about how to develop and manage a nuclear workforce.

A well-trained workforce is not the end product of a nuclear energy program; the cheap and reliable supply of electric power and safe plant operation and maintenance is. The latter is contingent as much on an efficient workforce as it is on efficient machines.

Chapter 6

Lessons for Newcomer Countries from Nuclear Energy Programs

The case studies presented in this work examine the manpower policies of six nuclear energy programs- namely US, France, Japan, Korea, China and India.

Nuclear programs that faced similar challenges and have adopted comparable strategies were grouped together.

Emerging nuclear energy countries can learn several lessons from the experiences of these six nuclear energy programs. These lessons, taken from three groups of countries are applicable to different stages of a new nuclear program.

The first set of lessons taken from China and India are applicable to a country that is installing and expanding nuclear capacity. The second set taken from France, Japan and Korea apply to manpower policies needed for the localization of and standardization of reactor technology. The third and final set are applicable to a nuclear industry that has reached steady state and must sustain its existing workforce, while leaving open the option of future expansion.

6.1 Lessons from China and India

1. Use of domestic and international education and training

International training here refers to training given at nuclear plants or facilities outside the country of interest. However, education and training can also be given locally to domestic nuclear plant workers by foreign scientists and engineers from the vendor country. The Chinese and the Indian experiences indicate that both domestic and international training is needed for meeting the manpower needs of an expanding nuclear energy program. While universities and technical schools may be able to expand to provide education in nuclear engineering, the practical experience gained through on-the-job training of reactor designers, regulators or plant workers is most effective for rapidly acquiring the required expertise.

Newcomer countries should, instead of hiring plant operators from the vendor country, employ the reactor vendors' engineers for educating and training its own plant workers. Having a domestic workforce that is able to able to design, operate and regulate nuclear plants leaves open the option of a future expansion of nuclear capacity.

2. Developing multiple reactors while expanding installed capacity

Both China and India face challenges in developing a workforce of regulators, reactor designers and plant operators for installed capacity comprised of diverse reactor designs. A nuclear energy program must be able to train and educate plant workers, regulators and designers in adequate numbers to meet the needs of growing installed nuclear capacity. This task is further complicated if reactors from different vendors or based on different technologies are being built at the same time. Diversity in reactor designs precludes the use of central training facilities for reactor operators. Such a strategy also creates a need for regulators capable of regulating and licensing multiple reactor technologies and also for licensing operators for each reactor type.

The lack of centralized training may hinder the communication between workers from different utilities. Nuclear reactor operators are trained and licensed to operate specific reactors. Diversity of reactor designs could hinder the mobility of reactor operators and other plant personnel and this could in turn slow down learning rates for the nuclear industry.

Newcomer countries would do well to keep in mind the challenges associated with simultaneously developing multiple reactor technologies. Although exclusive support for a single reactor technology could result in the lock-in of an inferior technology [59] , the economic benefits associated with standardizing and developing a single reactor technology are signficant. These benefits extend to a reduction in the diversity of regulation procedures, the ability to centralize training facilities and a faster learning rate for the industry as a whole.

However, it must be pointed out that both China and India seem not to have chosen the path of technology standardization. Both countries have solicited multiple reactor vendors and the presence of multiple nuclear utilities in China may have created some competition on the operation front as well. All of this suggests that these larger nuclear energy programs may have judged that avoidance of lock-in and the benefits of competition on the supply and operation side will outweigh economies associated with standardization.

Smaller newcomer countries, however, having more modest plans for their nuclear energy programs and only a limited capacity to iterate over reactor designs and technologies may benefit more from opting for lock-in and standardization early on and exploiting all of the economies described earlier.

6.2 Lessons from France, Japan and Korea

1. Technology transfer and localization

The French, Japanese and Korean nuclear industries have successfully localized American reactor technologies and have, through a process of standardization and incremental improvement, benefitted from faster learning rates and the localization of reactor design and construction capabilities. Both Japan and Korea initially used turnkey contracts for reactor construction and increased the participation of domestic firms in subsequent nuclear plant projects. Domestic firms initially acted as subcontractors for nuclear plant construction projects but experience gained through on-the-job training by foreign vendors allowed domestic firms to take on the responsibility of main contractors for future projects. Standardization of reactor designs also opens up the option of rotating workers from plant to plant. This, again, could increase learning. Countries having insufficient local expertise should opt for turnkey contracts. Subsequent localization of reactor technology is feasible for a future expansion of intalled nuclear capacity.

2. Centralized training

Another major advantage of having a single or at most two reactor designs is the ability to have centralized training facilities for nuclear plant workers. All three countries have centralized training facilities for reactor operators and maintenance workers. Education and training given in this way has likely ensured a uniformity in the skill-sets and proficiencies of plant workers across the industry in each country. The management and proficiency of nuclear plant workers is necessary for safe plant operation. We conjecture that having a uniformity in the skill sets of plant workers across the industry minimizes the differences in plant performances across the industry, i.e. there will be fewer 'good' and 'bad' plants and efficiency and safety standards will be higher for the industry as a whole.

6.3 Lessons from the US

1. Managing an aging workforce

The median age of the American nuclear workforce hovers around fifty and it is expected that half of the existing nuclear workforce will retire in the next five years. Nuclear programs that are continuously expanding installed capacity are less likely to face the problem of attrition due to retirement. The demands of an expanding nuclear program are met by expanding education and training infrastructure and hiring new workers. The US nuclear industry reached a steady state in the early 1990s and no new reactors have been built since. The low turnover rate for the industry as a whole has meant that nuclear plant workers have held their jobs and aged.

The US now faces the dual problem of replacing the aging workforce and documenting tacit knowledge that is likely to be lost when plant workers retire. Newcomer countries should implement procedures for documenting operating procedures from the outset. Tacit knowledge should be identified and passed on to future generations of plant workers. Lastly, although a low turnover rate could reduce training costs associated with training new plant workers, in the long run a moderate turnover rate is desirable for bringing in younger workers into the industry and also for transferring potentially useful knowledge to other industries through a transfer of workers.

2. Coordination with universities

Newcomer countries should organize nuclear energy programs such that there is a strong coupling between R&D centers, the regulatory body, utilities and universities. Such a coupling will ensure that the demands of all of these institutions are adequately communicated to universities. This will help avoid an imbalance in the supply and demand of manpower currently seen in the US nuclear industry. University collaboration can be increased though joint research projects and also by siting R&D centers in proximity to universities.

3. Self-regulation and manpower development

Finally, perhaps the most important lesson to be learned from the US experience is the benefit of self-regulation. We refer here to the role that INPO has played in improving the safety and efficiency of nuclear plant operations. Nuclear utilities themselves, rather than regulators, are best able to identify deficiencies in operating procedures and training practices. That is not to say that self-regulation modeled after INPO should replace regulation by an independent body. Self regulation should complement an independent regulatory organization and improve its operation by providing it inside information as INPO has the ability to do. A self-regulating organization such as INPO can disseminate crucial information about plant operation and incidence detection but also about effective training methodologies for plant workers.

Chapter 7

A Comparative Study of Workforce Development at the US Airlines, and Nuclear and Coal Plants

7.1 Introduction

Having examined manpower development strategies in the nuclear industries in the US, France, Japan, Korea, India and China, we now attempt a cross-industry comparison within the US. The structure and manpower development policies of the US nuclear industry are recapitulated and compared with those of the US airlines and coal-fired power plants. The US nuclear industry has experienced functional specialization accompanied by a plant-level shift in occupational composition. Through this study, we aim to identify whether similar trends were seen in the aviation and coal industries. Further, causes of specialization and shifts in occupational composition, where seen, are identified. We also establish that there are both similarities and differences in manpower development across these industries. Finally, lessons for newcomer nuclear energy countries are extracted.

7.2 Observations on the US Nuclear Industry

During the course of this work the following was observed about the US nuclear industry: at its inception, the US nuclear industry had a highly skilled workforce. However, over time specialization of work has been accompanied by a shift in educational qualifications. Highly skilled workers now constitute a significantly smaller fraction of the workforce than they did in the 1970s. Whereas in the 70s, scientists and engineers made up close to 30% [13] of the plant workforce, they now constitute close to 12% [8]. We find this shift non-trivial and attempt to explain its causes as well as identify whether the airlines and coal plants have seen a similar extent of specialization and change in educational backgrounds of their workers.

The following section describes the structure and organization of each industry. The third section lays out educational and training practices.

7.3 Structure and organization of the Industries

For all three industries, the focus is on the workforce involved in operations and maintenance. We are therefore interested in nuclear reactor and coal plant operators, pilots and maintenance workers for each industry. However, in order to better understand where and in what numbers these workers are needed, who they interact with and what their work environment looks like, we examine the structure and organization of each industry as a whole before turning to the education and training practices prevalent in each industry.

7.3.1 Nuclear Plants

There are 104 operational nuclear reactors in the US, 35 of which are BWRs and 69 PWRs. This number is set to increase at least by two after the NRC granted combined construction and operation licenses for two reactors at Georgia Power's Vogtle Plant and for two more at the VC plant in South Carolina.

Reactors in the US are operated as plants made up of either a single reactor or multiple collocated reactors. The largest plant, Palo Verde, has three collocated reactor units. A single unit plant on average employs 800 people and two-unit plants employ close to 1200 workers [24].

Nuclear plants directly employ 129,249 workers. Of these workers 74.8 % are on site employees, 13.3% are offsite corporate employees and 11.9% are contractors [23]. Initially the ownership of these plants was highly fragmented. However, beginning in the early 1990s, divestitures led to a consolidation of ownership. Ten companies now own more than 70% of the installed nuclear capacity. Horizontal aggregation of ownership has arguably improved information sharing and management of these plants that now have lower staffing levels on a levelized basis and lower operational costs [53]. This period of ownership consolidation was also accompanied by increasing capacity factors that have, since 2000, been consistently over 90%.

The NRC oversees the regulation and control of civilian nuclear power in the US. Among its duties is the licensing of reactor operators.

7.3.2 Coal Plants

The installed coal capacity in the US is 338 GW. 43% of the electricity consumed comes from coal [60]. The coal plant fleet consists of 1158 generating units. The size of a coal unit can vary from less than 50MW to 1300MW [7]. Figure 7-1 shows the distribution of the number and sizes of coal plants.

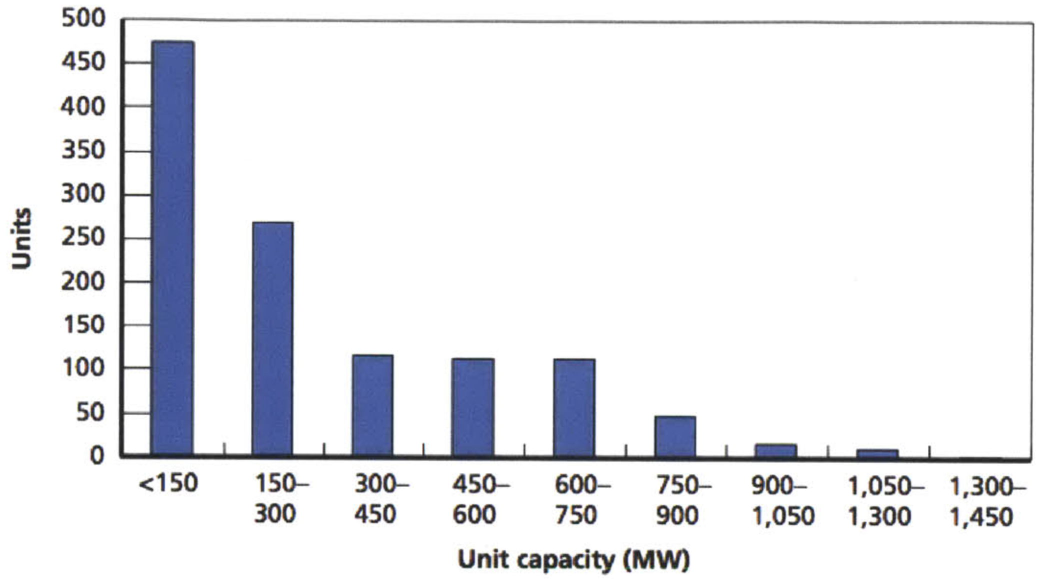


Figure 7-1: Coal fired electricity generating units [7]

Like a nuclear plant, a coal plant may consist of more than a single unit. Most of the coal plants in operation today were brought online in the 70s and 80s and are now between 25 and 40 years old.

Regulatory uncertainties about the reduction of greenhouse gas emission through the implementation of carbon taxes or a cap and trade system have contributed to a slow down of the coal industry. The installed coal capacity in the US is forecasted to increase by just 2GW between 2012 and 2035 [7].

Interestingly, companies that manufacture components for coal plants also do so for nuclear plants. Examples are Babcox and Wilcox, Doosan, Foster Wheeler and Hitachi Power all of which manufacture boilers for coal plants [7]. Similarly, utilities and companies that own and operate nuclear plants also operate coal plants. Examples are Duke and Entergy. Both industries also use the same engineering, procurement and construction firms (EPCs).

7.3.3 Airlines

The five largest passenger airlines in the US are Delta, United, Southwest, American, and US Airways. There are an additional 27 regional airlines [61]. Together, national and regional airlines in the US collectively employ 70,800 airline pilots, copilots and flight engineers [62]. In the 1980s, airlines employed many more maintenance personnel. However, a shift from service to price-based competition led to a number of layoffs[63]. The percentage of employees furloughed ranged from 8.3% in 1980 by American and 13.6% by Continental in the same year. The majority of these workers are thought to have been maintenance and engineering staff [64].

The Federal Aviation Administration (FAA) , an agency of the United States Department of Transportation regulates civil aviation in the US. Commercial and airline pilots must hold FAA licenses that are periodically renewed.

7.4 Education and training

We now examine the education and training practices in each industry. Similarities and differences are summarized in a subsequent section.

7.4.1 Nuclear Plants

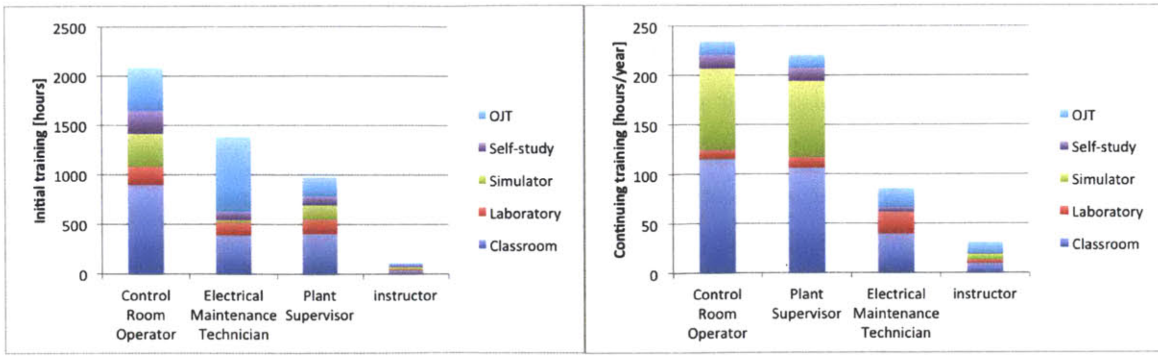
The first nuclear plants in the US were built by incumbent utilities, who were typically operating coal plants at the time. These utilities had, over time, broken down operating procedures into simple tasks relegated to medium and low-skilled workers, and they sought to apply this division of labor at the outset of nuclear plant operation. However, licensing criteria for plant operators adopted by the AEC required these utilities to set up training courses for plant operators. Furthermore, technicians working on nuclear plant construction had to be specially trained to build and assemble equipment at nuclear grade. Ad hoc training schools were set up for boilermakers, pipe-fitters and welders to train them in time for new plant construction.

Initially, and until the late 70s, government institutions assumed the responsibility for training high skilled workers who were absorbed by both nuclear utilities and vendors. However, over time, plants set up in-house training facilities.

Today, nuclear reactor control rooms are operated by six shifts of operators. For these operators, every sixth shift is a training shift. Not only operators but also electrical, instrumentation and control, chemistry and radiation technicians receive both initial and continuing training.

Figure 7-2 shows average initial and continuing training times at US plants. The IAEA survey [6] that collected these data showed large variations in training times across US plants. As an example, the total initial training for control room operators ranged from 270 to 2040 hours. These variations can, in part, be explained by differences in management and ownership of these plants , as well as differences in sourcing new hires, particularly if some of these plants hired more reactor operators from the nuclear navy as compared to others.

It does appear that the specialization of labour that the utilities sought to impose has been achieved. A high school diploma is a sufficient educational qualification for all levels of plant work.



(a) Initial training (b) Continuing training

Figure 7-2: U.S. Nuclear : Training plant workers [6]

Specialization is necessarily accompanied by narrowing the skill-set of workers. It has also had other impacts. Plant staffing levels increased in the 80s. This was due to regulatory pressures post TMI that created additional work at the plants and also increases in the numbers of managers. At the time, plants had multiple layers of management with narrow spans of control. Specialization of work had increased the need for integrators and , as a result, increased both cost and staffing levels. Cost control measures in the 1990s, hiring freezes and benchmarking staffing caused plants to reexamine organizational structures and reduce the layers of management and overall staffing levels [22].

The hiring freezes of the 1990s have caused plant workers to age in their jobs. Initial training times have decreased and continuing training times have correspondingly increased to meet the needs of an aging workforce whose skills must be updated as needed [6].

The median age of the US workforce today hovers around 50 and it is expected that half the workforce will retire over the next five years. In the face of large scale attrition, it is expected that nuclear plants will need to hire and train new workers in large numbers. Historically, classroom and simulator training times in the US have been high and on-the-job training times have been low. On-the-job training requires experienced plant workers for training new hires individually or in small groups. As the pool of experienced workers shrinks and the the number of new hires increases, it is likely that the quality of on-the-job training will suffer.

Long equipment life times and slow technological change have sheltered nuclear plants from innovation. Nuclear plants are largely isolated from research and development in nuclear engineering. Utilities have chosen to partner with technical colleges rather than universities to renew the worker pipeline. An example of such a cooperation is the National Uniform Curriculum Program (NUCP) [25].

Nuclear plants have also historically relied on the navy as a source of reactor operators.

7.4.2 Coal Plants

Due to the wide range of of coal-fired unit capacities, the size of the workforce at a coal plant shows larger variation than those of nuclear plants. Coal plants employ managers, foremen, electricians, mechanics, instrumentation and control technicians and operators. A coal plant can have a workforce as small as 75 people. Nuclear plants often employ 100 or more security personnel alone. Single-unit nuclear plants have staffing of around 0.8 staff/MWe. Coal plants however, were already reporting average staffing levels of 0.25 staff/MWe in the 1960s [13]. Although we do not have current data on coal plant levelized staffing, we expect that coal plants have smaller workforces across the range of installed capacities due, in part, to fewer and less restrictive security measures.

Like nuclear plants, coal plants too have partnerships with community colleges and themselves run apprenticeship programs that last from two to four years. Coal plants too face the problem of an aging workforce and several recent studies [30, 25] have expressed concern about the ability of coal plants to meet their manpower requirements.

Coal plants have typically had high specialization of labour. However, it appears that 'tight' labour markets may cause coal plants to reverse this historical practice. These plants use both their own full time employees and external contractors for plant maintenance.

A large number of plants spend more than 75% of their budget for a particular type of maintenance for hiring contractors . Of late coal plants have begun to cross-train operators as electrical and instrumentation and control technicians. This will allow operators to carry out maintenance work during plant outages and simultaneously reduce needs for external contractors. This cross-training is limited to plant operators. Technicians are not cross-trained to perform other functions [65].

Minimum educational qualifications vary from plant to plant. While the majority of plants accept high school graduates, some require trade school diplomas and others, associate degrees. Coal plants have rigid wage structure and some plants may require workers to help out for a year before hiring them as full time workers [7].

Perhaps the major source of technical change at coal plants has been the installment of pollution control measures and this has created manpower requirements. However, coal is still perceived as being "dirty" and it is getting increasingly hard for coal plants to attract new workers.

7.4.3 Airlines

Of the three industries, the aviation industry appears to have the largest proportion of high- skilled workers. The pool of pilots from which airlines hire means that pilots on average have more flying experience than is required by airlines.[1] Airlines also prefer that their pilots have university degrees.

The large pool of qualified candidates could be due to the fact that the aviation is seen as a dynamic and exciting industry. The industry faces less regulatory uncertainty compared to the

[1] Airlines require new pilots to have clocked at least 4000 flight hours. [62]

other two industries .

A study on aviation careers identified five pathways or pipelines of airline pilots. These are military training, foreign hires, on-the-job training, collegiate training and ab-initio training. This study also posits that these different pipelines create different kinds of pilots. Military pilots must pass stringent physical and mental aptitude tests and train rigorously. Military pilots on average also have more flight experience. It is for these reasons that airlines have historically preferred military pilots [66].

The military has been the largest contributor to the pool of pilots. Of these five pathways, foreign hiring is the least important due to an adequate domestic pool of pilots. People working in the aviation industry such as technicians may also, without military service or flight school attendance, become pilots by passing FAA tests and clocking the minimum number of flying hours airlines require.

Students can choose to study aviation-related subjects at an undergraduate level while simultaneously earning a pilots license. Finally, FAA certification may also be acquired by attending one of over 1700 flight schools in the country.

These last two pathways are the most expensive for the pilot herself and may cost as much as a medical school education [66].

This variety of worker pipelines has resulted in the large airlines not investing in initial or ab-initio training themselves. These airlines hire pilots released from military service or from regional airlines. As a result, the latter face attrition rates as high as 50% [66].

Airlines do, however, pay considerable attention to continuing training, the organization of which is a complex task. Because airline pilots spend considerable amounts of time away from their home bases, the use of instructors and simulators must be optimized to ensure that pilots receive training when needed in order to retain their licenses and in a manner that that minimizes costs for the airline itself. Delta, for example, was forced to reduce its workforce and re-organized training following the slump in business after September 11, 2001. It developed an algorithm for generating training schedules for individual pilots. It allows pilots to bid for assignments and assigns training schedules to minimize the total cost of training while maximizing the use of expensive simulators, standardizing training and ensuring that pilots, particularly those on probation, are trained as needed [67].

We do not notice a trend towards specialization in the aviation industry and certainly not for pilots. If anything, there has been a trend towards increasing the skill level of workers. The size of the industry and the large available pool of pilots has allowed airlines to demand both high educational qualifications and flight experience from the pilots they hire.

7.5 Similarities and Differences

Having examined the the size and structure of each industry we now identify some similarities and differences between these industries which later enable the identification of lessons that the nuclear industry should or should not learn from these industries.

In several ways the nuclear industry has more in common with the aviation industry than with coal. Both (the former) are 'high hazard' industries. Accidents in both industries are low probability high consequence events and an accident anywhere is an accident everywhere in that it affects the public's perception of the industry as a whole.

Both industries are based on technology that was developed for defense purposes through federal funding. Further, the armed forces have historically been an important source of workers for both industries. But the supply of military pilots and naval reactor operators is shrinking today.

There are in fact several similarities in the roles of pilots and nuclear reactor operators. Both work in shifts and often at irregular hours. Both must train rigorously for both normal operating and emergency procedures. Takeoff and landing and startup and shutdown are the hardest tasks for pilots and reactor operators respectively. Both are trained extensively for emergency procedures using simulators.

Pilots as well as reactor operators must periodically renew their licenses and for this purpose receive continuing training. Power plant operators must pass power plant maintenance (MASS) and plant operators (POSS) examinations administered by the Edison Electrical Institute. However these are one-time examinations and do not have a periodically recurring component needed for retaining licensure [68].

There are limited opportunities for advancement within the cockpit and the control room. A cockpit crew is comprised often only of a pilot and a co-pilot whereas a control is made of two or more reactor operators, auxiliary operators and a senior reactor operator. Responsibilities of individual workers in cockpits and control rooms are well defined in FAA and NRC regulations.

Airline and utilities (nuclear and non nuclear) cooperate with community and technical colleges for maintaining the worker pipeline.

A main difference between airlines and nuclear plants is the volume of each industry. Whereas there are 70,800 airline pilots [62], there are less than 5000 reactor operators. This order of magnitude difference has implications for education and training. The large demand for pilots means that flight schools run as profitable businesses for training pilots and the cost of initial training is born by the pilot herself. The smaller number of reactor operators means that nuclear utilities bear the large initial cost of training and licensing reactor operators.

Another chief difference is the extent of labor mobility. Attrition rates for large airlines were not found in literature, however, regional airlines have attrition rates of 50%. This number has in the past been closer to 10% for nuclear plants [22] but will likely be higher over the next decade due to retirements. With the establishment of new and expansion of existing nuclear programs, the global demand for reactor operators will increase rapidly. The demand for experienced reactor operators in newcomer countries and its implications for cross-national mobility is worth considering. This alone could perhaps justify the setting up of reactor operator 'training schools'.

7.6 Factors Affecting Specialization

We now discuss the factors that that affect the educational qualifications of workers and, over time, cause specialization.

Technological Change

Piore (1968) explains that that technological change creates demands for new workers and skills that do not yet exist. When this occurs, the designers or the engineers themselves may have to serve as the first generation of operators. These engineers then train their successors who have lower educational qualifications. A technician trained by an engineer may be able to train a grade school graduate. Participation in the process of production temporarily removes the designer from design and innovation but he returns to the process of design with new knowledge of operation. As a result, future generations of the technologies are neither radically different from the technology of the previous generation nor just incremental improvements but some hybrid of both [69].

Returning to the earlier point of technological change, the highly-skilled designer-engineer, so to speak, 'hands off' the technology to his or her successor and this process over time results in the shift towards a workforce with lower skill levels. This certainly seems to have been the case for the nuclear industry where the first generation of reactor designers and engineers operated and tested the research reactors they designed. Also, test and startup engineers employed by reactor vendors were often hired full time by the utilities.

This process of technological change has implications for education and training. Although high-skilled workers may be needed at the outset, the need for these workers may decline as the industry and technology matures. If the highly skilled workers are able to produce faster learning, then the shift to a lower skilled workforce may also gradually occur when incremental cost reductions as a result of learning are less than the costs of retaining a highly skilled and paid workforce. An industry must therefore be somehow able to anticipate both technological change and , to the extent that the system of education and training is endogenously determined, adapt it to produce the sorts of workers that are are needed. This process can be said to have taken place at nuclear plants. Initial training times in the early decades of nuclear plant operation were high. However, as the workforce has aged, training too has been adapted and continuing training times have increased.

This process of technical change and a shift towards a workforce with lower skill levels is not inconsistent with the process through which specialization occurs. This process is now examined further.

Cost control and Specialization

Specialization may occur in response to cost control measures. Specialization of tasks can increase the speed, efficiency and consistency with which they are performed. This may improve operational performance and reduce costs. However, specialization not only creates demand for lower skilled workers or workers with a narrower skill set, but it also creates demands for a new kind of worker, an integrator or a manager. As the extent of specialization increases so do the demands for these integrators. This suggests that there may be some optimal level of specialization at which operational costs are minimized and the identification of this optimum may require a process of trial and error.

This phenomenon was seen at nuclear plants. With the coal plant as the model, utilities that owned both coal and nuclear plants sought to achieve high levels of specialization that were prevalent at coal plants. While a high level of specialization was desirable and sustainable at a coal plant with a smaller workforce, the same extent of specialization created a need for large numbers of managers at nuclear plants.

At the end of the 1980s nuclear plants had as many as five and six layers of management and costs of integration were high. Beginning in the 1990s, these plants were divested and plants with high operating costs were bought by utilities and companies that owned better performing plants. In an attempt to reduce costs, new organization structures were explored and industry-wide benchmarking led to a significant decrease in the numbers of managers. Today, nuclear plants have at most two layers of management. It appears that nuclear plants, have, through a process of trial and error, actually identified an optimal level of specialization, or at least one that has for the last decade served them well. This may no longer be the case. As both nuclear and coal plant workers retire in increasing numbers over the next several years. It may make sense for power plants to cross-train workers, i.e. reduce specialization and also the size of their workforces. Coal plants that have started cross-training operators as electrical and I&C technicians have already taken a step in this direction.

7.7 How Are Airlines Different?

Airlines however, do not face worker shortages and have an abundant pool of pilots from which to draw new hires. Deregulation of the industry in the 1980s changed the way airlines competed, i.e. there was a shift from service based competition to price based competition [63]. At the time airlines trimmed their maintenance workforces to reduce costs but pilot training appears not to have suffered. Airlines were once again forced to trim workforces post September 11, 2001. However, even then, and Delta's reorganization of training schedules suggests this [67], pilot training was organized better rather than reduced, in order to reduce operating costs.

How are airlines different and why was a shift to lower-skilled workers and specialization not used to reduce costs?

It is conjectured here that there are three important reasons for this:

First, multiple and large worker pipelines that produce well-trained pilots with several thousand hours of flight experience [2] have removed the burden of initial training from airlines. The education, training, licensing and flight experience that pilots must acquire before being eligible for work at a large American airline is acquired over half a decade. It is hard to imagine that a utility would be willing to train a reactor operator for this length of time before he would be allowed to obtain a license and operate a reactor. Specialized tasks require focused and narrow expertise and these workers can be trained faster.

Second, the spatial confines of a cockpit also limits specialization and the cockpit is at most manned by three people. There is less room for redundancy. A larger cockpit would result in both a larger fixed cost and a recurring cost of space lost that could otherwise be used for seating additional passengers. There is no recurring cost associated with having a larger control room. Senior reactor operators can verify work done by their subordinates.

Finally, equally important factors are the size and outlook for the industry. Large airlines can attract commercial pilots or pilots from regional airlines. Other than naval reactors, nuclear plants have no such equivalent and coal plants have none at all. Research reactors could serve as such an alternate worker pipeline but here too, volume is insufficient. Airlines are expanding both globally and domestically, whereas there has been a lull in new build of coal and nuclear plants domestically. This has possibly contributed to a reluctance on the part of third parties undertaking the prohibitively large costs of investing in and training reactor operators.

7.8 The Problem With Specialization

Integration issues

We have already identified the integration issues associated with excessive levels of specialization. The experience of nuclear plants in the 80s shows that integration is more cost intensive when the scale of operation and the size of the workforce is large. Arguably, coal plants have been able to sustain higher levels of specialization because of fewer people needed for the operation and integration of fewer and less complex sub-systems.

[2] large airlines on average require 4000 hours of flight experience from their new pilots

Wrong Signals to New Industries

High levels of specialization and the use of low skilled workers is an appropriate manpower policy for an industry based on a mature technology. The shift towards specialization and a lower skilled workforce occurs over time and new industries would be unwise to do what the US nuclear industry did at its inception, i.e., model its workforce after that of the coal industry's.

Given the similarities between the US nuclear and airline industries, it might be said that the nuclear plants should really have modeled their manpower policies after those of airlines. However, the size of the nuclear industry would have prohibited such a practice had it been conceived at the time.

The most important lesson to be learned here is perhaps not for the US utilities but for newcomer countries that are planning on building new nuclear plants. Utilities in these countries may attempt to model the composition and size of their nuclear plant workforces after those in the US. The 'technology hand off' process described earlier through which technology transfer occurs from the designer-engineer to the operator suggests that, at least at the outset, high-skilled workers are needed to receive the knowledge needed to operate new equipment. Nuclear plants in newcomer countries will require highly skilled workers to receive tacit and codified information from engineers and trainers from the vendor country. It is clear that if these plants model their workforces after those at US plants today, they will underestimate manpower requirements. Alternately, modeling their workforces off of those at nuclear plants in the 1970s or 1980s would also be the wrong strategy because the knowledge gained through a process of trial and error from operating those plants can be passed on to reactor operators in newcomer countries.

7.9 Lessons for Nuclear Industries

Creating New Worker Pipelines

One of the strengths of the airline industry is the presence of multiple and robust worker pipelines that alleviate the need for long initial training times for new hires. Nuclear plants too would stand to benefit from institutions that could train reactor operators. Particularly at a time when the domestic industry is expecting large scale worker attrition even as the global industry anticipates expansion, national or shared facilities that provide classroom instruction coupled with simulator training for reactor operators would allow the nuclear plants themselves to focus on the important task of continuing, on-the-job training.

It is unlikely that any training schools would have the resources to invest in 'reactors solely for training new operators. However, an increase in the number of university research reactors or even construction of demonstration plants would provide opportunities for training reactor operators while simultaneously serving as research facilities.

Flexible Training Schedules

Reactor operators work in fixed shifts, and, as previously mentioned, every sixth shift is a training shift. Having a large number of pilots who are spread out geographically prevents airlines from training pilots in regular shifts. Instead, pilots are allowed to bid for assignments and training times. This minimizes costs of training and increases use of teaching resources. Utilities owning multiple plants could adopt a similar system of bidding for reactor operators to rotate newer workers from plant to plant. Potential entrants to the nuclear industry are discouraged by its rigid wage structure and procedural monotony. Flexible work and training schedules could make nuclear plants more dynamic and welcoming workplaces and also potentially accelerate inter-plant learning.

Avoiding Specialization At the Outset

As already mentioned, the most important takeaway from this study is for newcomer countries. These countries will have to make several choices regarding the training, size and educational qualification of their workers. These newcomer countries must not attempt to replicate the composition seen at US plants but instead employ highly skilled workers, at least at the outset, to speed the process of technology transfer from the vendor country. Having large numbers of medium and low skilled workers who are unable to internalize knowledge from trainers and the vendors engineers could have repercussions for plant performance and safety.

7.10 Conclusions

At the outset of this study, we expected to find similarities in education and training across the three industries. Some of these similarities are the ways in which reactor operators and pilots are trained at nuclear plants and by airlines. Continuing training practices in these two industries are similar. The major differences lie in the initial training and the educational qualifications of workers in these two industries. There is a marked trend towards increasing skill-levels of pilots and, more recently, those of coal plant operators. To the extent that cross-training workers reduces manpower requirements, we expect to see this trend towards broadly trained workers at nuclear plants too.

This chapter and previous case studies indicate manpower development and worker pipelines show more cross-national than cross-industry similarities. The system of universities, technical schools and community colleges (or their equivalent) , apprenticeship programs and plant level initial and continuing training exist in all of the countries whose nuclear programs were studied. Although this system of institutions exists in all the nuclear energy programs studied, these institutions have assumed varying levels of responsibility and have had vastly different levels of success in each country. Community colleges have yet to replicate the successes of technical colleges in France and Japan for training technicians in large numbers.

However, only in Korea [3] do we find an equivalent of a 'flight school' for the nuclear industry. Although the individual sizes of the nuclear industries in the studied countries may not justify creating such institutions, a global demand for reactor operators for new nuclear programs may well justify nuclear reactor operator training schools perhaps in the US or jointly operated by newcomer countries in close proximity to each other.

[3] We refer here to the KEPCO International Nuclear Graduate School described in Section 3.6 of Chapter 3.

Part II

The Manpower Development System

Chapter 8

Forecasting Manpower Requirements and Implications for Education and Training

8.1 Why Newcomer Nuclear Energy Countries Should Forecast Manpower Requirements

Countries that are planning nuclear energy programs will need regulators, plant operators, technicians, maintenance workers, security personnel and managers in adequate numbers for the safe and efficient operation of their nuclear plants. Some of these countries may even move to localize nuclear energy technologies and develop domestic research and development capabilities.

However, several of these countries do not already have in place the system of institutions that will be needed to educate and train a nuclear workforce. Experiences of countries that already have nuclear energy programs shows that this system consists of universities, technical colleges, apprenticeship programs and plant level training initiatives for both initial and continuing training. Further, experiences of countries studied earlier in this work, and particularly that of the US, indicates that it is not enough to simply have these institutions in place but to also sustain a dialog between them in order to prevent a mismatch between demand and supply of labour.

Countries that are about to embark on new nuclear programs may choose to create domestic infrastructure or institutions for education, training and research while also simultaneously making use of existing institutions elsewhere. The high costs associated with creating this infrastructure suggests that government initiative and funding will be needed, at least initially.

In the early years of the US nuclear energy program, the AEC, predecessor to the DOE, set up training centers for scientists and engineers while simultaneously providing stimulus for the creation of nuclear science and engineering departments at universities. Regulatory incentives provided by the AEC in the form of licensing criteria for reactor operators led to plants setting up in-house training centers.

Planning and regulatory bodies in newcomer countries will need to play a similar role. However, the extent of the involvement of planners and regulators in creating education and training infrastructure will depend on the projected scale of the nuclear program and the numbers of workers needed for various activities. The timing and magnitudes of investments to be made in research and development will depend on the numbers and kinds of workers that will have to be trained. Forecasting manpower requirements several years ahead is essential. This is due in part to the long lead times associated with setting up new departments within universities and technical schools, and training certain kinds of workers. In certain countries starting from scratch, the trainers themselves will first have to be trained.

In this chapter, we briefly review methodologies that have been used in the past for forecasting manpower requirements. A system dynamics modeling tool developed at the Los Alamos National Laboratory is then used to determine the manpower requirements associated with a single reactor. Implications for lead times for training different kinds of workers are then explored.

8.2 A Review of Manpower Modeling Methodologies

At a symposium titled "Manpower Requirements and Development For Nuclear Power Programs" organized by the International Atomic Energy Agency in Vienna in 1980, several countries presented their methodologies for forecasting manpower requirements. The conference proceedings indicate that planners at the time recognized that a lack of manpower could prove to be a bottleneck and delay the progress of a new nuclear program. Countries such as the US and France used the sizes of workforces at existing plants as reference values and extrapolated these requirements to the turn of the century to determine the number of workers that would need to be trained and hired annually. Similarly, countries that at the time were planning new nuclear energy programs, namely Turkey, Philippines, Japan, India and Brazil used similar methodologies to predict the sizes of their workforce. It was acknowledged that domestic capabilities for education and training workers were insufficient and contracts with reactor vendors would need to include provisions for training new workers [18].

More recently, the centrally planned nuclear energy programs in France and Korea project their manpower requirements at least five years ahead. France and Japan extrapolate manpower requirements to future installed nuclear capacity [15], whereas Korea uses measures of labor productivity, forecasted learning rates and future sales of electricity from nuclear plants to predict manpower needs. Such projections have been made up to 2030 [45].

In the US, Entergy uses a systems dynamic tool to forecast attrition due to retirements and bases its hiring strategy on the results of its model [34]. The UK is planning a nuclear revival and is similarly forecasting manpower needs [70].

8.3 Nuclear Power Human Resource Modeling Tool

The Nuclear Power Human Resource Modeling tool was developed at the LANL in collaboration with the IAEA as part of the Global Nuclear Energy Partnership Infrastructure Development Working Group's activities. This model was constructed using a systems dynamics software called iThink.

The model consists of two linked modules, "reactors" and "workforce". The former tracks the lifecycle of reactors i.e. design, licensing, construction, operation, life extensions and decommissioning and the latter tracks the manpower requirements associated with each stage of the reactor life cycle. The workforce module distinguishes between national 'pools' of engineers, technicians and craftspersons. Users of the model can specify the initial age composition of the workforce and track retirements and hiring requirements over time [41].

Primary user inputs to the model are starting electricity demand and its growth rate and the fraction of the demand that will be met by nuclear power. The model uses a single-unit US plant as the reference plant. [1]

For our purposes, the model was used to output the manpower requirements for a single PWR unit. The data from this simulation is presented in the following section. The data presented here is limited to manpower requirements in the construction and operation phases and the composition of the workforce during these respective phases.

8.4 Manpower Requirements for a Single PWR Reactor

The reactor life cycle is shown in Figure 8-1. The reactor application phase lasts for a period of three years, construction ends in year sixteen and is followed by reactor operation. Reactor decommissioning is not shown the figure.

Total construction and operation manpower requirements are shown Figure 8-2.

The model further distinguishes between different construction workers: boilermakers, carpenters, electricians, iron workers, insulators, laborers, masons, millwrights, painters, pipe fitters, sheetmetal workers and teamsters. The operations workforce consists of these construction workers as well as workers divided into seven process areas : reactor operation, equipment reliability, material services, support, training, work management, configuration management and loss prevention. The

[1] A more detailed description of the model can be found in Reference [41]

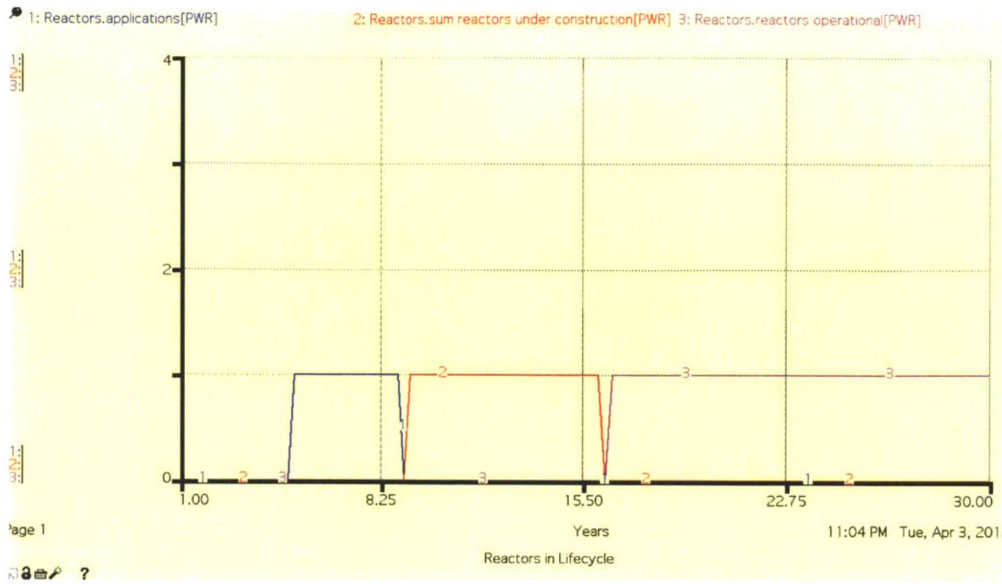


Figure 8-1: Reactor Life Cycle

model assumes that the composition of the workforce remains constant over time, i.e. the ratios of different kinds of construction and operations workers do not change over time.

The peak construction workforce is 1472 workers and the total operations workforce, which, once reactor operation begins remains constant, is 867 [2].

8.4.1 Proposed Changes to the Model

The version of the model provided by LANL takes the rate of increase of electricity demand and the nuclear fraction of the total installed capacity as inputs. However, most newcomer countries already have reactor deployment schedules in mind. Future work on the model should decouple reactor deployment from electricity demand such that the model directly takes a reactor deployment schedule as an input. This would increase the utility of the model for planners who are interested in evaluating manpower requirements associated with specific reactor deployment schedules.

Further, the model assumes that the size and composition of the plant workforce does not change over the life of the reactor or across successive reactors. As was discussed in earlier chapters, we have reason to believe that learning effects might lead to smaller and more specialized workforces. Changes to the workforce module of this model should be made to study the impact of specialization or reduction of the size of the workforce over time on the education and training requirements.

[2] This is an assumption made in this model. As discussed in an earlier chapter, the actual size of the workforce for a single unit plant in a newcomer country may in fact be greater than the estimate presented here and decline over time due to learning and specialization.

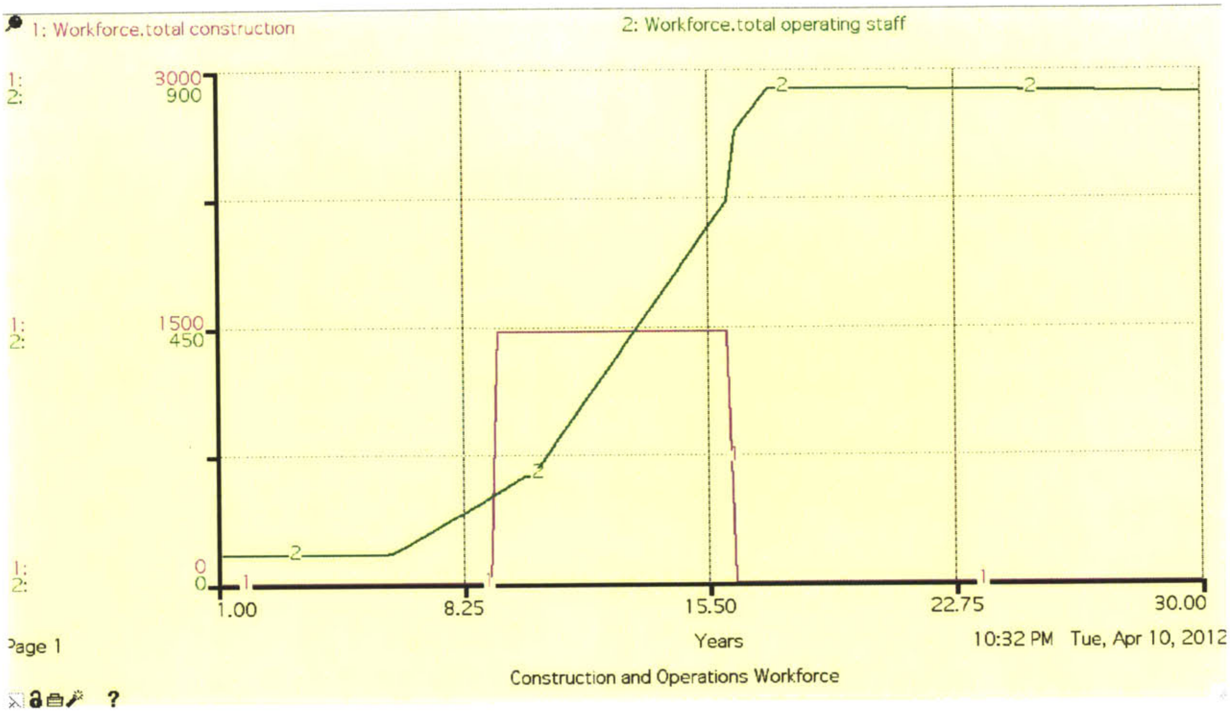


Figure 8-2: Total Construction and Operation Manpower Requirements

8.5 Considerations for Educating and Training Workers

We now turn to the question of lead times[3] required to train different kinds of workers and choices that countries may have for formulating education and training pathways for their nuclear workforces. These 'lead times' are made up both of education and training at a university or technical college and also training at the institution that employs the workers.

While planning for a nuclear workforce, countries should identify potential manpower supply bottlenecks while being mindful of the fact that these might occur even for types of workers whose training times are actually fairly short. As an example, training times for craft workers may be the shortest. However, craft workers are required in large numbers particularly during reactor construction. Inability of the architect-engineer firm to recruit craft workers in adequate numbers during plant construction would cause delays in construction schedules.

In the following discussion we distinguish between four categories of workers: craft workers, technicians, engineers, and scientists and managers. These workers may be further differentiated based on their specific roles. However, we make this higher-level distinction because of the similar training times and education and training options for these sets of workers.

[3]'Lead time' here is defined as length of time needed to train a worker in addition to his high school education.

Craft Workers

As the literature and the output of the NPHR model both indicate, craft workers are needed in very large numbers particularly during reactor construction. The model shows a peak craft worker requirement of 1472. However, the actual number of workers needed for construction will depend in no small part on the education and training of these worker and management of the construction phase.

Because of the very large number of craft workers needed, these workers will likely be hired domestically and possibly in close proximity to the construction site itself.

Although high school education is not necessary, previous experience through apprenticeships or construction work at coal or gas plants is desirable. Minimum training times for these workers may be as low as 2 years, however acquiring a mastery of the profession may take longer –up to 4 years.

Even experienced workers may need to be trained to work with tighter design tolerances. For this purpose, either a vocational training center created specifically for nuclear construction workers may be set up or ad hoc training may be provided on-site and also on the job under the supervision of the vendors' or architect-engineer firms' engineers.

Creation of national or regional vocational training centers would likely have spillover effects for other industries by raising the average skill level of craft workers and standardizing initial training.

Following plan construction, several of the craft workers may be retained at the plant for maintenance work. Planners may also see fit to create construction or maintenance firms to absorb these craft workers. This strategy will be particularly useful for reducing construction times for subsequent reactor units while also reducing recruitment and training efforts needed for subsequent new build.

Technicians

Unlike construction workers who may be hired in time for reactor construction, technicians [4] must be hired before reactor operation begins. Depending on the occupational composition, technicians may comprise over half the workforce or 400 or more workers at a single-unit plant. Although this is a large number, depending on the complexity of future tasks, select numbers of these technicians may be sent to the vendor country to be trained on-the-job at the reference plant. Conversely, technicians from the vendor country may be brought over to the newcomer country for training technicians.

A high school education and additionally diplomas from technical colleges are desirable educational qualifications. A regional or national vocational training center would be useful for training technicians, particularly for radiation safety training and training and training with mockups of plant equipment. Minimum lead time for technicians is 3 years. This includes the 2 years needed for a diploma and an additional year of on-site training. This lead time may be longer if previous

[4] Further divided into electrical, maintenance, instrumentation and control, radiation protection and chemistry technicians

experience, particularly for electrical, maintenance and instrumentation and control technicians is desired.

Engineers and Scientists

Backgrounds in nuclear science and engineering for engineers and scientists working at the plant are useful but not strictly necessary. Previous knowledge of nuclear engineering may reduce initial training times at the plant.

Engineers and scientists too will need to be hired before plant operation commences. This is especially true of those who will be reactor operators. Engineers and scientists will initially comprise roughly a quarter of the plant's workforce and the number of engineers and scientists may decrease over time as specialization occurs.

Because engineers and scientists are needed in smaller numbers, the quickest and most efficient way of training these workers may be to send them to the vendor's country for training at a reference plant. The Korean experience suggests that contracts for hiring these workers may need to include return obligations to reduce attrition.

Lead times for these workers are roughly 5 years. This includes a 4 year university education and a year of training the reference plant or on-site.

Managers

The experience of the US plants indicates that multiple layers of management should be avoided and that managers should have broad spans of control. This suggests that managers will need broad knowledge of plant operation. Lead times for managers are the longest. In addition to a university education, previous experience at a power plant is desirable. An IAEA report recommends that newcomer countries should attempt to recruit expatriates or foreign nationals who have held management positions at nuclear plants in other countries [41]. Depending on experiential requirement, minimum lead times may be as long as a decade.

Some Additional Considerations

Several IAEA studies and country reports point to the effectiveness of training new workers at the reference plant. This indicates that vendors bidding for contracts in newcomer countries may choose to collaborate with utilities in the home country. Such collaborations may be easier in vertically integrated or centrally planned nuclear energy programs but harder for reactors vendors in the US. Additionally, the newcomer country may choose to draw several workers from its existing power plants.

Carroll points out the importance of the processes through which people are selected to work in an organization. New workers bring with them the work culture and mental models acquired at their former work places. These considerations are especially relevant for the management of a nuclear plant where the creation of a safety culture is paramount. New nuclear plants may choose to hire a combination of inexperienced workers, workers from coal or gas plants and from nuclear plants in other countries. "The culture of the organization thus will be reflected in the kind of personnel it attracts and socializes, and the kind of learning it encourages and permits."[5] We recognize the creation of the 'right' kind of culture is particularly important because besides having affecting safety, it may be propagated to subsequent plants. Planners would do well to keep in mind the implications of hiring decisions and minimum educational requirements on the creation of a safety culture.

Table 8.1 summarizes the minimum lead times for each of the worker types discussed above.

Table 8.1: Lead times for educating and training workers

Worker	Minimum Lead time [years]
Craft workers	2
Technicians	3
Engineers and Scientists	5
Managers	10

Conclusions

In this chapter, tools that planners may use for workforce development are presented along with considerations for education and training of different types of workers. These discussions also presented some choices that planners may face in developing manpower for a new nuclear energy program. The chapter that follows begins by addressing how planners may approach the question of manpower development. A fuller range of choices available for training workers is explored in conjunction with how feasible choices may be identified and decisions regarding workforce development made.

[5]For a thorough treatment of this topic please see Reference [71].

Chapter 9

Creating a Manpower Development System for a New Nuclear Energy Program

The previous chapter outlined the kinds of workers that are needed for a new nuclear energy program, the kinds of institutions where these workers are needed , and equally importantly, the institutions that educate and train these workers. We choose, therefore, to think of the task of creating a workforce for a new nuclear energy program in terms of the design of a system of institutions and the linkages between them. We do not find that there is a unique solution, or, in other words, a one-size-fits all system of workforce development that will serve all newcomer countries equally well.

The design of this system, among other things, depends on the projected scale, pace and motivation for the nuclear energy program. A full set of factors that have been identified are discussed later in this chapter.

The institutions and the linkages between them are unique to each country. By 'institutions' we mean entities that either predominantly supply or demand manpower and 'linkages' here refers to flows of people, information and funds that may be determined by contractual relationships, geographical proximity, organizational and cultural norms, and pre-existing systems and structures in the society.

We expect the 'ideal' system for each newcomer country to look different. For example, a large country may choose to create centralized and shared maintenance and construction workforces to be rotated from plant to plant. The economies associated with the creation of such a shared body of workers may not be significant for a smaller nuclear energy program that may choose instead to rely on local labour for a one-time construction project and full-time plant staff for maintenance and repairs.

Getting the design of these individual institutions and of the system as a whole right is paramount because of its impact on safety, learning and performance for the nuclear industry as a whole. Centralized organizations that rotate workers from plant to plant may facilitate the transfer of best practices and accelerate learning, reduce costs and ensure higher levels of safety. However, excessive centralization may remove from the sphere of control of the plant certain activities, such as on-the-job training, that it is best able to perform.

We identify three levels of decision making that are needed for the design and creation of this system and it is to the discussion of these decisions that we now turn.

9.1 Three Levels of Decision Making

We think of the construction of a manpower development system as requiring three levels of decision making. These are shown in Figure 9-1. The first two levels consist of strategic decisions whereas the final set of decisions are implementational and directly determine the design of the system.

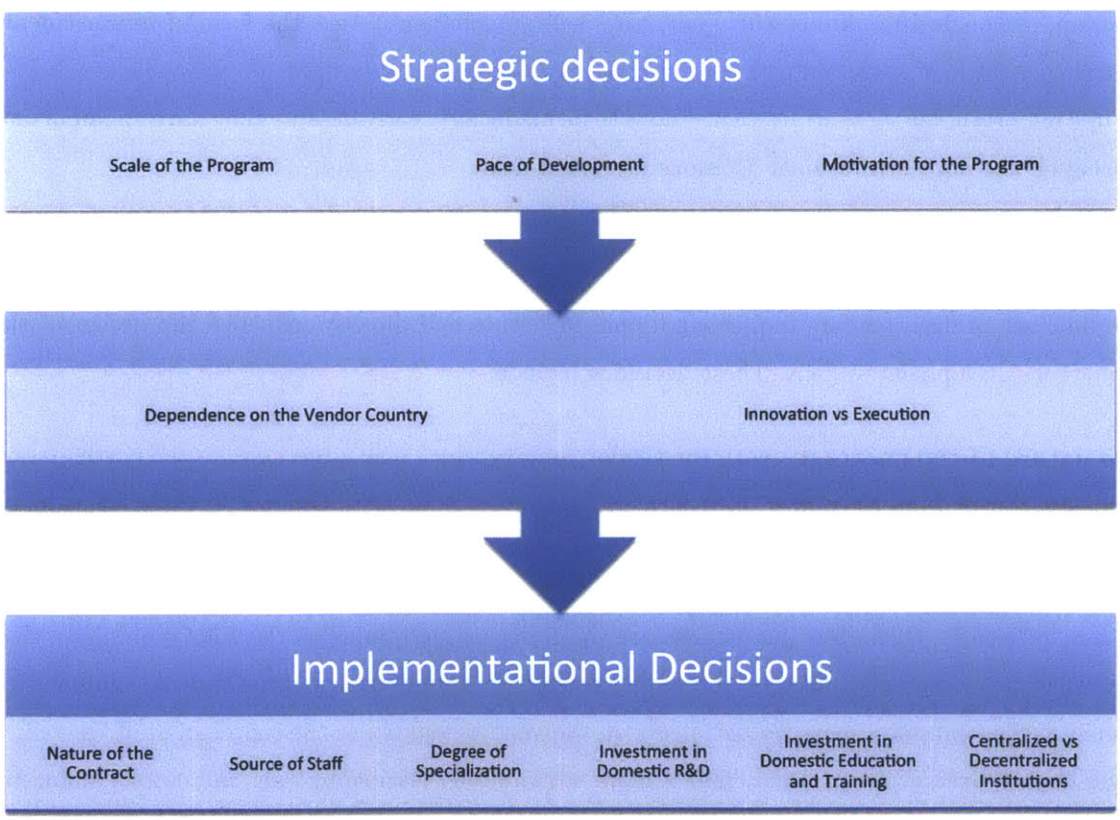


Figure 9-1: Strategic and implementational decisions for the creation of a manpower development system

Strategic Decisions

The first two levels of decisions are strategic in nature. The first relates to the nature of the nuclear program itself, i.e. its projected scale, pace of development and the motivation for initiating it. The motivations may take the form of a desire for cheap, reliable, carbon neutral source of electricity or reduction of dependence on foreign supplies of coal or gas or even the creation of a nuclear program as a vehicle for economic development.

The second set of strategic decisions are concerned with the relationship with the vendor country. A newcomer country may choose to rely indefinitely on the vendor country as a source , not only of the initial technology transferred, but also of innovations and manpower. In addition to its relationship with the vendor country, a newcomer country may also find it useful, early on, to define the innovative or executive extent of the program. We define an 'innovative' program as one that may commence with the deployment of known reactor technology but that over time, creates new variants of it or new reactor designs altogether. An innovative program may also be willing to take greater technological risks associated with building and operating untested reactor designs. Conversely, an 'executive' program focuses on the deployment and operation of known designs. For a such a program, although innovations will occur, they will predominantly take the form of improvements in management and operation rather than changes to the technology itself.[1]

It is important for these strategic decisions to be made fairly early because they have an important bearing on the implementational decisions described next.

Implementational Decisions

The final set of decisions are implementational in nature and directly influence the design of the manpower development system. These decisions include:

The nature of the contract with the vendor country which may either require the participation of domestic firms from the outset, or a turnkey contract, a Build Own Operate Transfer contract or a Build Own Operate one.

Source of Staff Of no less importance are the decisions pertaining to the source of staff - that may either be all domestic, all from the vendor country or a combination of the two. A country with a small nuclear program may choose to rely on the vendor country as the source of staff whereas a larger nuclear energy program may find it more economically feasible to train and employ domestic workers.

[1] The differences between the 'innovative' and 'executive' nuclear energy programs as they are defined here may be though of in the context of the four-stage innovation model developed by Lester and Hart (2011) [72]. An innovative program will concern itself with creating options whereas an executive one will focus on improements-in-use.

The Degree of Specialization of tasks and the occupational composition of the workforce influences the rate at which technology transfer and therefore localization can occur. Specialization therefore affects the pace of development. Further, to the extent that high-skilled plant workers are able to communicate better with engineers and scientists involved in problems of design, a lower degree of specialization may accelerate iterations over initial technology, development of improved reactor designs and therefore the ability to innovate.

Investment in Domestic R&D capabilities are needed for reducing dependence on the vendor country over time and also for a shift from execution to innovation.

Investment in Domestic Education and Research Investment in domestic R&D necessarily requires investment in education and research. Creation of nuclear engineering as well as other science and engineering departments at universities, that train scientists and engineers in adequate numbers, will be essential for creating the manpower for research and development facilities.

Centralized vs Decentralized Institutions As discussed earlier, countries with modestly large nuclear energy ambitions may find it feasible to create centralized construction and maintenance workforces to minimize costs and accelerate inter-plant learning. Similarly, centralized training centers may also be created for nuclear plant operators and maintenance workers to ameliorate the burden of initial training on the plant itself.

These decisions , made sequentially, can be thought of as several possible combinations of 'if, then' statements, each of which leads to the design of a specific system. The if-then linkages developed in this work are influenced by the countries studied earlier. Four possible systems representative of newcomer countries are explored in the section that follows.

9.2 Four Possible Systems of Manpower Development

Although estimates vary, close to 50 countries have expressed interest in nuclear energy in recent years. Of these, three countries have ordered nuclear plants and six have started preparing infrastructure for developing nuclear energy. Based on our hierarchy of decisions, these nine countries can be broadly divided into three groups of small to medium sized nuclear energy programs based on our interpretation of their strategic decisions. To these we add China and India , which comprise a fourth group, as a means to contrast and highlight possible options for the creation of manpower development systems. Table 9.1 shows a list of newcomer countries along with the planned installed capacity of their nuclear energy programs, projected date, vendor country and contract type. Of these, three countries have finalized agreements with reactor vendors. The planned capacity and projected dates for the others are likely to change or become more concrete in the near future as contracts are signed.

Small - Executive

We define a Small-Executive nuclear program as having a projected scale of 2000 MWe or less. We find that a smaller projected scale is characteristic of a country having smaller geographical extent and a lower level of economic development. Periodic fluctuations in electricity demand imply that nuclear energy, which provides constant baseload power, can only comprise a fixed portion of the electricity demand that does not vary over time. Countries having smaller economies and electricity consumption are therefore less likely to invest in multiple plants. The limited extent of the nuclear energy program implies that its motivation is more likely the production of cheap, carbon-free electricity rather than the direct stimulation of economic development.

Further, a smaller size may increase a tendency towards dependence on the vendor country and an execution rather than innovation based strategy.

The contract is likely to be BOO or BOOT. Low demand for domestic research and development is likely to result in smaller investments in education and training, a greater degree of specialization and reliance, at least initially, on the vendor country for providing or training staff. In such a case, limited geographical extent and concentration of electricity demand, as well as economies associated with reactor collocation might result in reactors being co-sited. This eliminates the need for centralized construction and maintenance workforces and the plant is likely to rely on full time staff for both operations and maintenance. Construction workers will be hired locally and some of them may be absorbed into the plant workforce at the end of construction. The creation of a single technical school or a nuclear engineering department may be sufficient to meet the manpower needs of such a nuclear energy program.

Medium - Executive

A Medium-Executive program has a projected scale of greater than 2000 MWe but less than 5000 MWe. This may amount to two nuclear plants with multiple reactor units at each site. The 'executive' nature of the program as we define it implies a reliance on the vendor country. We expect the system for manpower development to resemble that of the Small-Executive program except in the extent of investment in domestic education and research and the centralization of institutions.

This program may choose a single technology and stagger its reactor deployment schedule. It may rely on the vendor country for training and also for staff for the first plant but eventually use workers from the first plant to train and manage those at the new plant. Further, having more than a single site justifies the creation of a centralized maintenance workforce following the completion

Table 9.1: New Nuclear Energy Programs. 'BOO' = Build Own Operate , 'BOOT' = Build Own Operate Transfer

Status	Country	Planned Capacity [MWe]	Projected Date [a]	Vendor Country	Contract Type	Reference
Nuclear Plant Ordered	Belarus	2400	2017	Russia	Turnkey	[73]
	Turkey	4800	2021	Russia	BOO	[74]
	UAE	5600	2020	Korea	Turnkey	[75]
Developing Infrastructure	Bangladesh	2000	2018[b]	Russia	Turnkey or BOOT	[76]
	Jordan	1100[c]	2020	Russia	Turnkey or BOO	[77]
	Vietnam	4000[d]	2025	Russia	undecided	[78]
	Poland	4600	2030	undecided[e]	undecided	[77]
	Egypt	4000	2025	undecided	undecided	[77]
	Nigeria	4000 + SMRs	2025	undecided[f]	undecided	[77]

[a] for installing all planned capacity

[b] Projected date for the operation of the first reactor only

[c] An additional plant of the same capacity is also planned. On an even longer time scale, four VVER type reactors may be purchased from Russia [77]

[d] An additional capacity of 6700 MW is planned to go online by 2029

[e] Areva, GE Hitachi and KEPCO intend to bid for the contracts for these units [77]

[f] Russia is likely to build the large plants and US vendors are proposing SMRs [77].

of the second plant for servicing staggered plant outages. Having a common maintenance workforce for both plants reduces levelized O&M costs.

Medium - Innovative

This program has the same scale as the Medium- Executive program but a reduced reliance on the vendor. This program may opt for a Turnkey contract for the first plant and develop its own variant on the technology for the second plant. Although the modest scale of the program may not allow the R&D organization of this program to become a reactor vendor, it may collaborate with the original vendor for future contracts in other newcomer countries. This program may also be willing to take greater technological risks and build first-of-a-kind reactor designs.

Such a country may see its nuclear energy program as a vehicle for economic development and invest in local R&D capabilities to create beneficial spillovers to other industries.

We expect this nuclear workforce to be high-skilled. Interactions between plant workers and the engineers and designers of the R&D organization will be frequent and both sets of institutions will facilitate exchanges of information and personnel.

Large - Innovative

This nuclear program has an installed capacity greater than 5000MWe. The large scale of this program forces it to be innovative and less dependent on the reactor vendor as a means to reduce costs. This program is likely to solicit multiple reactor vendors, prevent the early lock-in of technology and invest heavily in rapidly augmenting domestic education and training, and R&D capabilities. The scale of this nuclear energy program will allow it to iterate over the vendors' original reactor design at subsequent plants by developing its own variants while also developing indigenous technologies.

This program is likely to partner with the vendor for future contracts in newcomer countries and also develop domestic vendor firms.

We expect this program to have a high-skilled workforce at the outset and a gradual specialization over time at plants based on older reactor designs. Such a program will also benefit from centralizing both construction and maintenance workforces.

There is also the possibility over time of withdrawal of government control and funding and greater participation of private firms in such a program.

9.3 Concluding Remarks

A decision-making hierarchy for the creation of a system for manpower development is developed in this concluding chapter. We identify two levels of strategic decisions and a final level of implementational decisions that lead to the creation of the manpower development system. Four possible systems and their characteristics are then presented as examples.

We propose that there is a correlation between scale and innovativeness. Larger nuclear energy programs are able to iterate over reactor designs and develop new technology while improving existing designs. The data gathered in the form of Table 9.1 indicates that the majority of the new nuclear programs fall under what we define here as 'medium' sized programs. Since programs of this size may either be 'executive' or 'innovative', these countries have an important decision to make with regards to their reliance on the vendor country. For this reason, it is essential that these countries carefully evaluate their motivation for initiating nuclear energy programs and make coherent strategic decisions.

We also see fit to point out that this approach to the design of a manpower development system is a quasi-static one. These systems are in fact dynamic and the role of institutions and the linkages between them may change over time with changes in the projected scale and pace of development. A 'Medium - Executive' program may, over time, evolve into a 'Medium-Innovative' one which might grow further into a larger program. It is likely that such transitions will be gradual and a well-designed system will be able to adapt itself to these changes.

In conclusion, we emphasize again that no one-size-fits-all solution exists for a manpower development system for every country and it is important, from the outset, to design a system, that serves the goals of the nuclear energy program of a newcomer country.

Chapter 10

Conclusions and Future Work

This work was based on case studies of the US , French, Japanese, Korean, Indian and Chinese nuclear energy programs. Additionally a cross-industry study that compared education and training in the US nuclear, airline and coal industries allowed the extraction of lessons for newcomer countries. A manpower development model from LANL was used to comment on manpower requirements for a single nuclear reactor and the implications for lead times for training different types of workers. Finally, based on knowledge gathered through these case studies, a decision-making hierarchy for the creation of a manpower development system was proposed.

While this work sheds light on how newcomer countries should create workforces for their nuclear energy programs, it raises several questions that were not answered here. These are listed and briefly discussed in conclusion.

First - What are the initial levels of specialization needed at the initial plants in a newcomer country? High educational qualifications and low specialization may accelerate technology transfer and create 'seed' workers for training the future workforce. However, the training of high skilled workers requires higher costs and lead times. Newcomer countries must perform some sort of cost-benefit analyses to determine an adequate occupational composition and level of specialization.

Second - How does specialization of work at the nuclear plant impact plant performance and safety? The contributions of individuals to aggregate metrics of plant performance such as capacity factors are difficult to isolate. Less aggregated indices may be needed for quantifying and studying the impact of specialization. Further, does specialization at nuclear plants narrow worker skills but increase expertise and proficiency or is the loss of a broader skill set accompanied by a loss of efficiency and interest in work due to a greater monotony of tasks?

Third - How will the institutions that supply and demand manpower attract the best students and workers respectively? It is likely that in several of these countries, measures that improve the public acceptance of nuclear power will increase enrollments and reduce the need for aggressive recruitment by nuclear plants.

Fourth - What will be the attrition rates for different segments of the nuclear workforce? Although this is hard to predict ex ante, a reasonable estimate is nevertheless needed to inform hiring, education and training policies.

Fifth - How can the benefits of education and training be evaluated and what metrics can be used for making this assessment? We have reason to believe that plants do not have sufficient incentive to train workers unless mandated to do so through regulations. This can be attributed to the fact that the impacts of education and training on plant performance and safety are not easily captured or quantified.

Sixth - How does a new nuclear program create positive spillover effects for other industries? It is possible that the education and training programs initiated for training the nuclear workforce will provide training opportunities for workers from other industries. How can these spillover effects be evaluated to encourage benefitting industries to jointly invest in education and training or to mobilize support for a nuclear energy program?

Finally - We recognize that education and training takes place not only at high schools, technical colleges, universities and training centers but at the workplaces themselves. If these places of work are also places of learning then the design of the manpower development system is part of a larger question - the institutional design of the nuclear energy program itself. Besides work being done by the IAEA, there is a surprising lack of literature that addresses this important question. Although the decision-making hierarchy presented in Chapter 9 sheds some light on how institutions may be designed relative to each other, introducing explicit considerations of cost, safety and performance of individual plants or the program as a whole may modify the designs of and linkages between the institutions we propose. This is an area of study that requires attention, particularly in light of the impending creation of new nuclear energy programs.

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